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Unraveling perceptions of wine complexity

New analysis for tannin "stickiness"

Describing white wine oral sensations

Oxygen transmission with different closures into bottled wine

Tannin: impacts, opportunities along the value chain

Microbial origins of key wine aromas, PART I: ESTERS and ALDEHYDES

SMART VITICULTURE Grape-specific trellises in Sierra Foothills vineyard

Myths of frost protection

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Cover Photo:
Transfer of sorted grapes to fermentation tank at Rodney Strong Vineyards.
Photo by Don Neel

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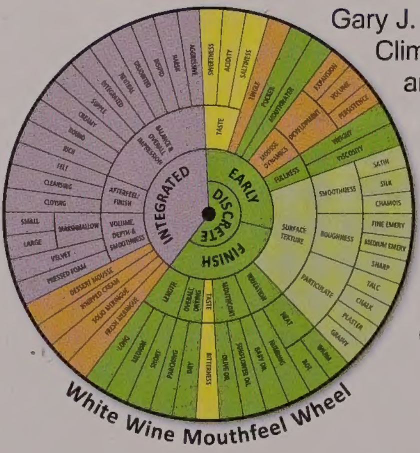

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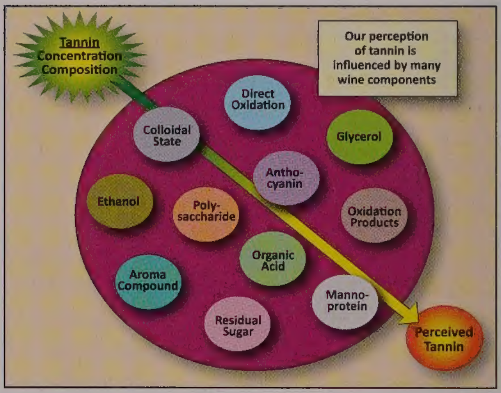

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Unraveling the nature of perceived Complexity in wine

BY **Wendy V. Parr,** Faculty of Agriculture
& Life Sciences, Lincoln University,
Christchurch, New Zealand
E-mail: wendy.parr@lincoln.ac.nz

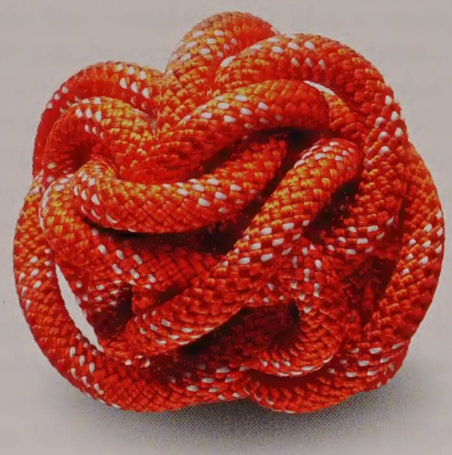
That wine is capable of providing us with great pleasure is well-documented historically through the arts and literature. More recently science has entered the picture, with published research concerning emotion and wine consumption beginning to elucidate the nature of the relationship between hedonics (i.e., pleasure) and wine.[2]

That wine also can cause us to think is perhaps less romantic but is equally well-documented, casting doubt on French philosopher Pascal's notion that emotion and cognition are separate systems that seldom interact.[4]

Emotion and cognition are very easy bed-fellows when it comes to wine. An everyday example is how a sip of wine can evoke memories of a past experience or encounter, the memories often highly emotional and autobiographical.[5]

But not all wines inspire either great emotion or much thought, despite their chemical composition being fundamentally similar and objectively complex (comprising many volatile and non-volatile components).[10]

If the ability of a wine to evoke cerebral (cognitive) and sensorial responses is not a given, what makes any particular wine encourage thought? A reasonable assumption is that a wine we consider "complex" has a higher probability of doing so than a wine we consider "simple."



The question then becomes "what differentiates wines that are considered more toward the complex than the simple end of the continuum?"

For example, are wines with many perceivable components the most likely to be considered complex and to challenge us intellectually and sensorially? Or, perhaps the converse, namely that well-integrated and seamless wines appear more complex?

Recent work by sensory scientists in France and New Zealand has begun to investigate just what constitutes perceived complexity in wine. Two studies are summarized below, each employing a very different methodology.

Mental representation of complexity in wine

A collaborative project between Lincoln University in New Zealand and the University of Paris VIII in France aimed to ascertain the specific wine attributes subsumed within the concept "complex" as a function of wine expertise.

Thirty wine consumers and 39 wine professionals from New Zealand and Australia were interviewed individually using a Free Association methodology to ask about their notion of complexity in wine under three study conditions: 1) wine complexity in general; 2) wine complexity in relation to white wine *vin de garde* (wine with potential to develop well in the cellar); and 3) wine complexity in relation to red wine *vin de garde*.[7]

In the first condition, participants were asked: "Thinking about wine, can you give the first words that come to mind when I say 'complex?'" Within a 10-second, time constraint a maximum of four words or expressions per person was recorded by the interviewer and these comprised the verbal data called "induced words."

Subsequent aspects of the procedure involved participants defining and elaborating upon their induced words (for example, ordering their induced words in terms of their importance to complexity in wine), and participating in the two subsequent conditions of the study.

Wine is capable of providing us with great pleasure; that wine can also cause us to think is perhaps less romantic. What makes any particular wine encourage thought?

Despite its Freudian roots, this free-association method is well-grounded in current models of memory and thinking and thus there are precedents for analyzing and interpreting the data from the participants' verbal responses.[8]

All responses from participants to the word "complex" were subjected to Alceste statistical analysis which begins by quantifying the words and expressions to provide word frequencies in the

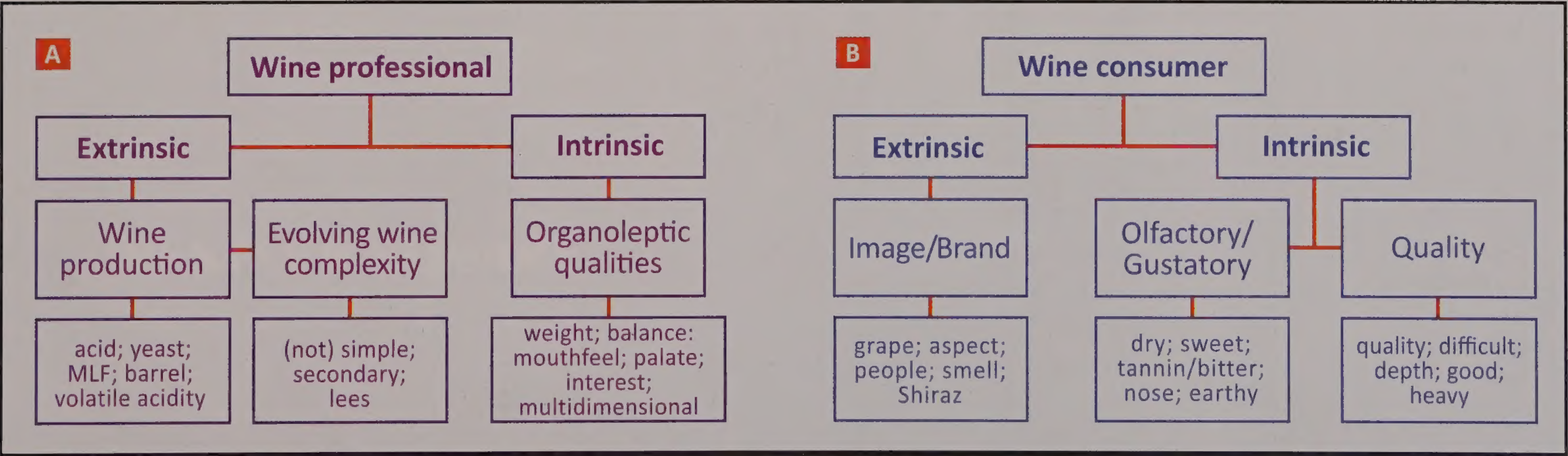

A
Wine professional
Extrinsic
Intrinsic
Wine production
Evolving wine complexity
Organoleptic qualities
acid; yeast; MLF; barrel; volatile acidity
(not) simple; secondary; lees
weight; balance: mouthfeel; palate; interest; multidimensional
B
Wine consumer
Extrinsic
Intrinsic
Image/Brand
Olfactory/ Gustatory
Quality
grape; aspect; people; smell; Shiraz
dry; sweet; tannin/bitter; nose; earthy
quality; difficult; depth; good; heavy

Figure 1. Dimensions of perceived complexity in wine as a function of wine expertise. MLF = malolactic fermentation. [Figure first published in *Food Quality & Preference*, 22, p. 657, 2011].

various study conditions.

Subsequently, the words in the frequency tables were classified as either Intrinsic (as part of the wine itself such as specific characteristics) or Extrinsic (those aspects that are important to the resulting character of the wine such as vineyard site, or type of enological processing, but not actually part of the finished wine) in keeping with a recently-published model of perceived quality in wine.[1]

Not all wines inspire either great emotion or much thought, despite their chemical composition being fundamentally similar,

The major result was a demonstration that complexity in wine appears a multi-dimensional, mental construct for both participant groups, but that wine professionals and wine consumers structure differently their mental constructs of complexity.

Figure 1 shows a simplified model of the group mental representation of complexity in wine in general (the underlying data are from the first condition of the study) for wine professionals and for wine consumers.

Figure 1-A presents the quantitative output data comprising frequency and importance of words evoked by wine professionals. For wine professionals, the most weight was accorded to extrinsic items such as processes and decisions relating to producing complex wine (such as choice of yeast).

Other responses were classified under "evolving complexity" and included dynamic factors (factors that change over time) implicated in development of complexity as a wine is developed (such as lees stirring). These latter aspects differed from factors included in the "wine production" category which pertained to additives (such as acids and malolactic bacteria) and tools such as barrels.

Figure 1-B has a visual representation of the wine consumers' data. Conversely, the statistical analysis showed the weight of items here to be on intrinsic factors such as pleasure associated with actual consumption of a wine, and specific organoleptic qualities giving rise to that pleasure.

In particular, wine consumers associated complexity with their notions of wine quality, employing terms such as "good," having "depth" and "more difficult to appreciate." The quantitative analysis showed that, to a lesser degree, wine consumers' construct of complexity included extrinsic factors, these being image and brand where they linked image of a wine to region of origin or name of winemaker. Price of a wine did not feature as an important factor for either consumers or wine professionals.

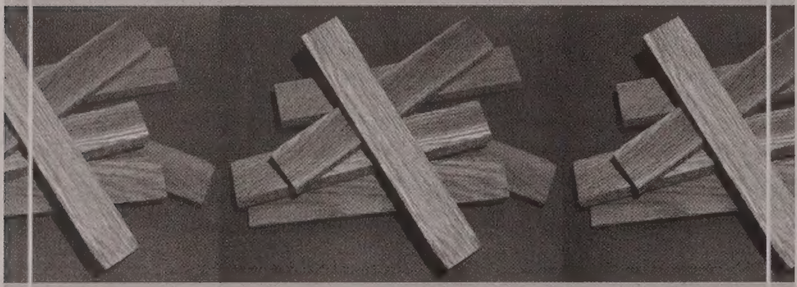
Perceived complexity in Sauvignon wine

The second empirical study to be summarized here employed a sensory methodology to investigate the nature of perceived complexity in Sauvignon Blanc wines. This study is a collaborative project between the University of Burgundy in France and Lincoln University in New Zealand.

Our interest was in unravelling the experiential nature of complexity in wine, and in particular to delineate the key sub-components or wine characteristics implicated.

Complex may be a single perception while being a multi-dimensional term.

Eighty-seven French participants (16 wine professionals, 30 wine connoisseurs, and 41 wine consumers) assessed



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perceived complexity of 13 New Zealand (Marlborough) Sauvignon Blanc wines by sensory methods.[9] The wines were part of an innovative commercial winemaking project aimed at increasing complexity in New Zealand Sauvignon Blanc wines.

> Perceived harmony and balance of a wine were linked positively with perceived complexity.

Participants assessed each wine via two sensory methods. First, free-sorting methodology was employed where participants were asked to classify or group the 13 wines in any way that made sense to them. Subsequently, participants provided three or four descriptors to each group of wines that they had formed to explain the criteria that they had employed to sort or classify the wines (for example, a faulty or fruity group).

Second, participants rated each wine on perceived complexity, using a questionnaire developed at the University of Burgundy specifically for this purpose. The questionnaire comprised eight items, an overall complexity rating along with a rating of seven assumed sub-components of perceived complexity (such as harmony and the number of identifiable flavors in a wine).

The main results included that participants considered the organoleptic qualities of intensity, harmony, length (persistence in mouth) and balance to be important contributors to perceived complexity, these varying somewhat as a function of taster expertise.

Most important, the data allow us to make a contribution toward current discussion of the major theoretical interpretations of stimulus complexity from fundamental psychological science. The relevant theoretical issue pertains to whether a multi-component stimulus such as a wine is perceived as more complex when its components are obvious (can be separated out) or when they are not individually obvious (the individual components are perceived as blended into a single perception).[3]

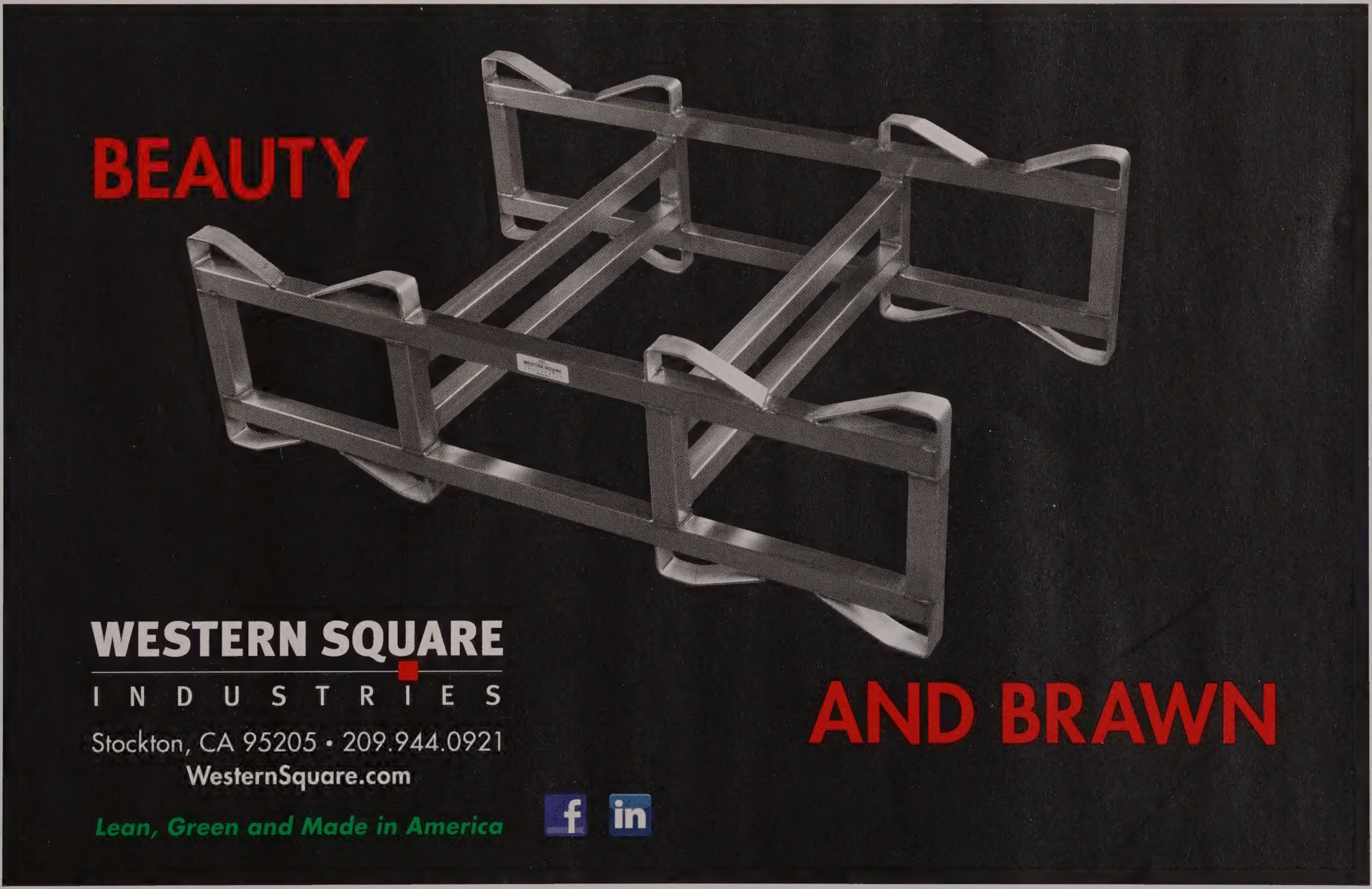
Our data demonstrate that participants in all three expertise groups were able to discriminate among individual components of the wines in the sorting task (separate the wines produced by "standard" Marlborough, Sauvignon Blanc production techniques from other, non-standard production wines). Despite this result, perceptual separability (ease of identifying the individual components/flavors of a wine) was not a factor positively associated with perceived complexity.

Conversely, perceived harmony and balance of a wine, presumably linked to degree of perceived integration, were linked positively with perceived complexity. From a theoretical perspective, this supports the notion that "complex" may be a single perception, while being a multi-dimensional term.

> Wine professionals and wine consumers structure their mental constructs of complexity differently.

In other words, the integration of aromas in a multi-component mixture such as a wine or a perfume may be considered a higher level of abstraction that can give rise to a single perception described by the word "complex."

This higher level of abstraction is argued as involving configural perception[3] or perceptual fusion where the multiple components of a stimulus are recognized as a whole pattern with the individual components not necessarily accessible to consciousness. That is, as distinct from elemental perception where the



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components of a mixture such as a wine are perceived within the mixture, configural perception involves blending of the components or properties of the mixture with the resulting percept or Gestalt[3] being different from the components.

> **The ease of identifying individual components/flavors of a wine was not a factor positively associated with perceived complexity.**

Evaluating global wine attributes such as complexity and perceived quality appears to involve cognitive processing that differs to that implicated when a taster evaluates a more concrete attribute such as intensity of a specific flavor like passion fruit.

Conclusion and application

It is clear that complexity in wine is a multi-dimensional, higher-order mental construct, comprising viticultural, enological and organoleptic aspects. Further, our data from both the study on mental representation and from the behavioural (tasting) study show that complexity in wine is a construct that varies as a function of wine-related expertise.

An application or take-home message from these results is particularly relevant to wine marketing personnel. Our data concerning differences between groups in how complexity is conceptualized suggest the following: Although wine professionals are interested in aspects of wine production such as vineyard location and enological processes, and often give priority to such information on the back label of fine wine bottles, wine consumers overall are not.

Wine consumers appear far more driven by their notions of wine quality and image/brand, and their expectations of an enjoyable and pleasurable sensory experience. PWV

Wendy Parr is principal research officer, Faculty of Agriculture & Life Sciences, Lincoln University, New Zealand. She has a Ph. D. in Psychology (Cognition and Psychophysics) and a Ph. D. in Wine Science (Sensory). Wendy is winemaker and partner in a boutique vineyard and winery in Nelson, New Zealand.

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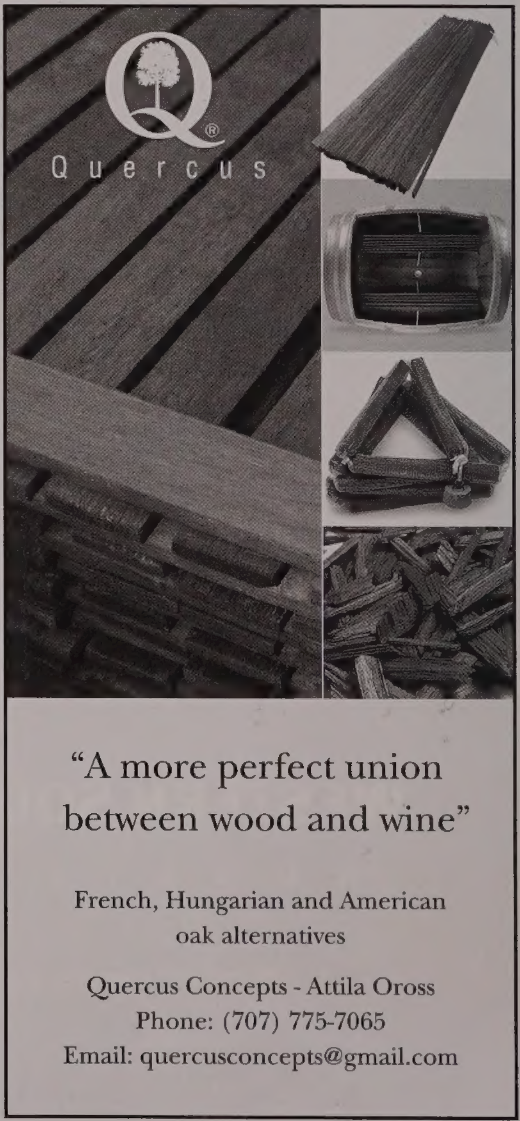

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COVER STORY

New vineyards yield grapes for red wine blend

BY Don Neel, Editor

A new Sonoma County red wine brand is in production at Rodney Strong Wine Estates, outside Healdsburg, Calif. The first harvest in 2013 was 350 tons from 200 acres of third- and fourth-leaf vines planted in 36 blocks over a 4,000-acre ranch. The ranch is part of a 19,000-acre ag set-aside under the Sonoma County Agricultural Preservation and Open Space District. Located 18 miles northwest of Healdsburg, the vineyard ranges from 735 feet to 2,035 feet in elevation.

"The 2014 harvest yielded an average of 3.5 to 4.8 tons per acre from fourth and fifth-leaf vines that are spaced 4 feet x 8 feet," says Doug McIlroy, director of vineyard operations. There is a vertical shoot positioned trellis, and the vines are head-trained and cane-pruned. The predominant rootstock is 101-14 with a small amount of 1103P planted.

The 2013 free-run wine will be blended from Cabernet Sauvignon (six clones) planted on 139 acres, in addition to 39 acres of Malbec (two clones), 7.4 acres of Petit Verdot (one clone), 3.5 acres of Cabernet Franc (one clone), and 2.9 acres of Merlot (one clone). There is also one clone of Zinfandel on 5.6 acres.

The 2014 harvest took 30 days to deliver between 20 and 80 tons per day to the winery.

Crush pad improvements

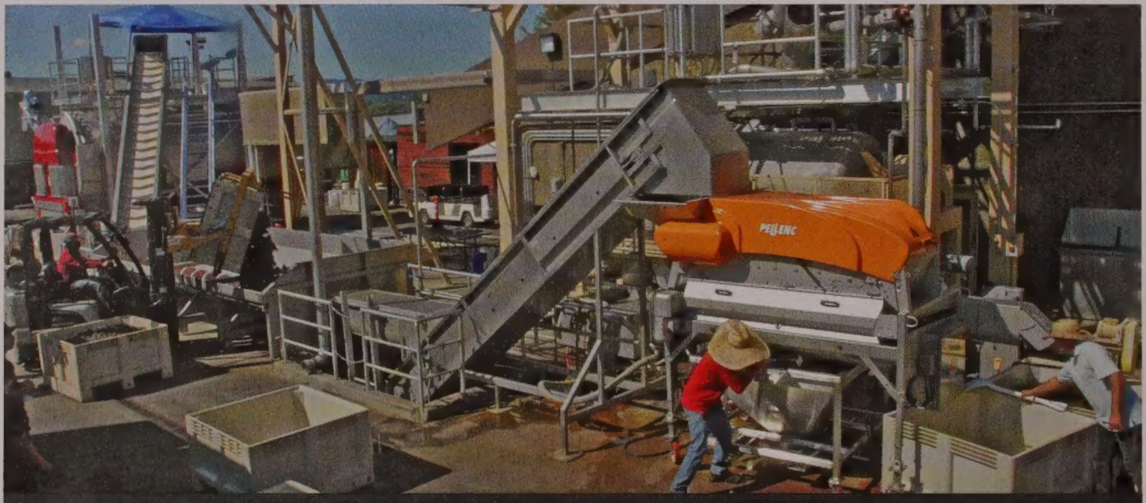
To handle the increased tonnage and ensure the wine quality that winemaker Justin Seidenfeld wanted, he and his team designed many upgrades to the existing crush pad.

"P&L Specialties was approached in 2013 to help find a creative and functional solution to the crush pad layout by adding both destemming capability and white grape receiving in an existing crush pad footprint," says Ed Barr of P&L Specialties. After examining many options, a creative and simple solution of converting an existing grape-receiving hopper into a bi-directional receiving hopper was chosen. The bi-directionality allows processing of red grapes on one end of the hopper and receiving and transfer of white grapes on the other end of the hopper.

In order for the existing hopper to undergo the drastic modifications, it was removed and sent back to P&L for modification. A new bi-directional 18-inch diameter variable pitch screw was fabricated and installed along with complete redesign and fabrication of the mechanical drive system.

The new crush pad includes the reuse of an existing cleated, incline belt berry-separator/feed-conveyor supplied years earlier on the "red" end of the receiving hopper, and addition of a new 30-inch-wide cleated incline belt conveyor on the opposite end to feed a new Bucher tank press.

A new 20-inch stainless-steel in-



Crush pad with receiving hopper, berry separator/sorter and tank press to use as a basket press.

Two high elevation Cabernet Sauvignon vineyards ready for harvest.

ground press discharge and incline pomace-removal system was installed to complete the crush pad. This crush pad is a compact and efficient use of space that provides the versatility to process both red and white grapes in the same location with one receiving hopper.

New berry separator/sorter

"The Pellenc Selectiv' Process Berry Separator/Sorter utilizes linear high-frequency vibration to achieve gentle separation of berries from the stems," says Lance Vandehoef of Pellenc America Inc. "This new technology works well to keep berries and stalks intact at the Rodney Strong Vineyards.

"A unique feature is that the Selectiv' Process unit allows loose berries to pass through a grid belt directly to an integrated and adjustable roller-sorting table prior to the linear berry separators. The first stage of the roller-sorting table separates any juice present and removes independent seeds and immature berries and raisins. The second stage removes jacks, petioles and other green material before discharge of the berries into a mobile transfer bin for delivery to a fermentation tank."

Rodney Strong Vineyards operated the separator/sorter at 12 tons per hour to achieve desired quality. Its maximum speed is 20-tons per hour.

New program to operate tank press as a "basket-style" press

The Bucher press programs available on the new 250hl tank press at the Rodney Strong Vineyards are part of the new model Bucher Xpert ICS (Intuitive Communication System). One specific program that allows the press to function similarly to a basket press is called "sequential pressing," explains Mea Leeman, sales director at Bucher Vaslin North America.

Sequential pressing is based on a series of inflations to pressure levels and holding times attained sequentially without performing any deflations of the membrane or rotations of the press. The value of the successive pressure levels range from 0 to 2 bars.

A forklift delivers a 1,500-pound capacity transfer hopper to the fermentation cellar to drop sorted grapes through a 12-inch diameter butterfly valve into a 12-inch screw sump that keeps the pump suction flooded of a 4-inch diameter Waukesha variable speed (0-220 gpm) positive displacement pump that transfers grapes into the fermentation tank.

When the tank press is filled with fermented material, the tank rotates 40 degrees to position the membrane at the top of the drum and the patented Bucher drain channels to be in the lower half of the drum, allowing gravity and pressure to release wine from the fermented grape skins.

The winery can program in advance or modify, in real time, up to 10 different "sequential programs" that contain up to 20 different pressing "steps." The pressing can be graphically displayed on a user-friendly Windows screen.

Sequential press programming is a standard press program installed on all Bucher Xpert presses. The specific "sequential pressing" exists on previous versions of the Xpert Series (Versions 1 and 2). However, deflation of the membrane without any rotation of the tank is made possible exclusively through the new Bucher ICS system.

When the tank press is loaded with fermented grapes after free run drain-separation of 24 hours from a 20-ton fermentor, the pomace is discharged from the press after a 90-minute press cycle.

New red fermentation cellar

To make the highest quality wine possible, Seidenfeld and his team designed a brand new fermentation cellar exclusively for this new brand in an existing 11,520-square-foot building. The remodel included re-sloping of the floor and insulating the walls and roof before installing 57 new La Garde stainless steel square fermentation tanks that maximized the space in the building.

Four inches of foam insulation were sprayed on the roof to achieve R30 value and insulation panels (total of 6 inches thick) were installed inside the walls to achieve an R40 value.

La Garde, a division of SML Stainless Steel Group in Canada, built the custom-designed wine tanks from 304 stainless-steel Grade 11. "La Garde square shape fermentors are designed to maximize the contact ratio of must to juice through a thinner cap to optimize fermentation," says Jostran Lamontagne of La Garde, "wherein lies the creation of flavor and complexity of the wine.

"With La Garde square tanks, the contact surface could be increased by up to 50% when compared to a cylinder with the same floor width. By increasing that contact surface for the same volume, you increase the efficiency of the fermentation process. You achieve more color, tannin and more flavors from the grapes with a cap of must that is thinner, much easier to facilitate pump overs and the cooling process. The square tanks can produce 30% more volume of wine than a round tank for the same wall width that you want to occupy.

"A big advantage of La Garde tanks is the simplicity to clean them, due to the hand-polish finish. The exterior wall is a number-four polished finish with polished welds. The interior wall is a 2B-polished finish with polished welds

A pump trial was conducted in the 2014 harvest with three fermentation tanks containing grapes harvested on one day from the same vineyard block to determine the optimum pump for pump over during primary fermentation. Pumps included: 1.5 hp RV65 with a helicoidal impeller, and a 5 hp RV80 with a helicoidal impeller. RV series pumps are widely used for pump over where high capacity and minimum destruction of solid parts (seeds, skins etc.) is required. The design of a pump contributes to a better extraction of tannin, reducing formation of lees to achieve higher quality wine. The third pump, a 2-inch air pump that handled 140 gallons per minute at 100 psi, was chosen for pump overs in the future with an air pump to be installed with every fermentation tank.

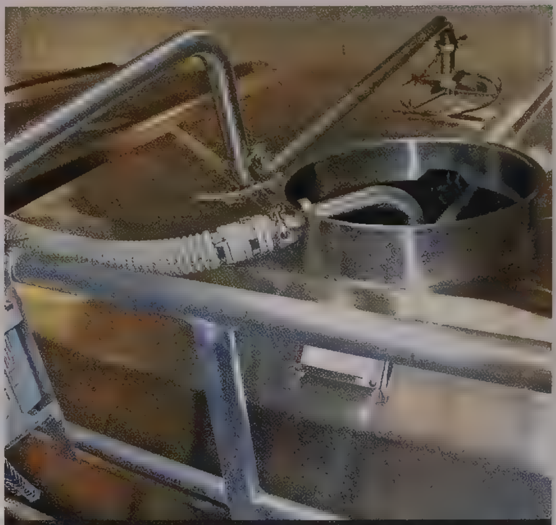
that are seamless. Although the tanks have a rectangular shape, the inside is rounded with no sharp corners."

La Garde fabrication has been preceded by seismic design objectives to resist an earthquake of level 6 on the Richter scale. The Rodney Strong 6,000-gallon tanks were designed following a finite element analysis. Two structural braces were welded around the tank and reinforced corners support the base of the tank. La Garde supplied special circular metal collars that limit the movement of the tank's six feet (see photo on page 13).

Dimensions of the 6,000-gallon (20-ton grape capacity) tank are 115 inches (side walls), 112 inches (front and back walls), 127 inches tall from the 2% slope floor that is 34 inches above ground. There are six breakdown tanks: two 1,250 gallons, two 1,000 gallons, and two 750 gallons.

Cooling/heating capability on new tanks

"The 6,000-gallon fermentation tanks have two sets of tank wall channels for recirculation of chilled or warm glycol to give winemaker Justin Seidenfeld close and constant temperature control," explains Bob Heasell, senior engineer at Applied Process Cooling Corp. (APCCO).



A "toad" irrigator was installed inside the truncated manway at the top of the tank to perform a 20-minute pump over supplied by a 2-inch air pump three times per day.

Depending on the temperature of the fruit being received, the two tank wall-channel system allows for either cooling or warming of the fruit.

In the 2014 harvest, grapes typically arrived at the winery at 70° F and were chilled for three days in tanks with chilled glycol in tank wall channels to lower the fruit temperature to 50° F. On the third day, the fruit was allowed to begin to warm up naturally to assist the initiation of primary fermentation, and the system continued to precisely manage the tank temperature.

During the cooling mode, both the upper and lower jackets provide cooling based on a TankNet controller activat-

Glycol piping on tank back wall.

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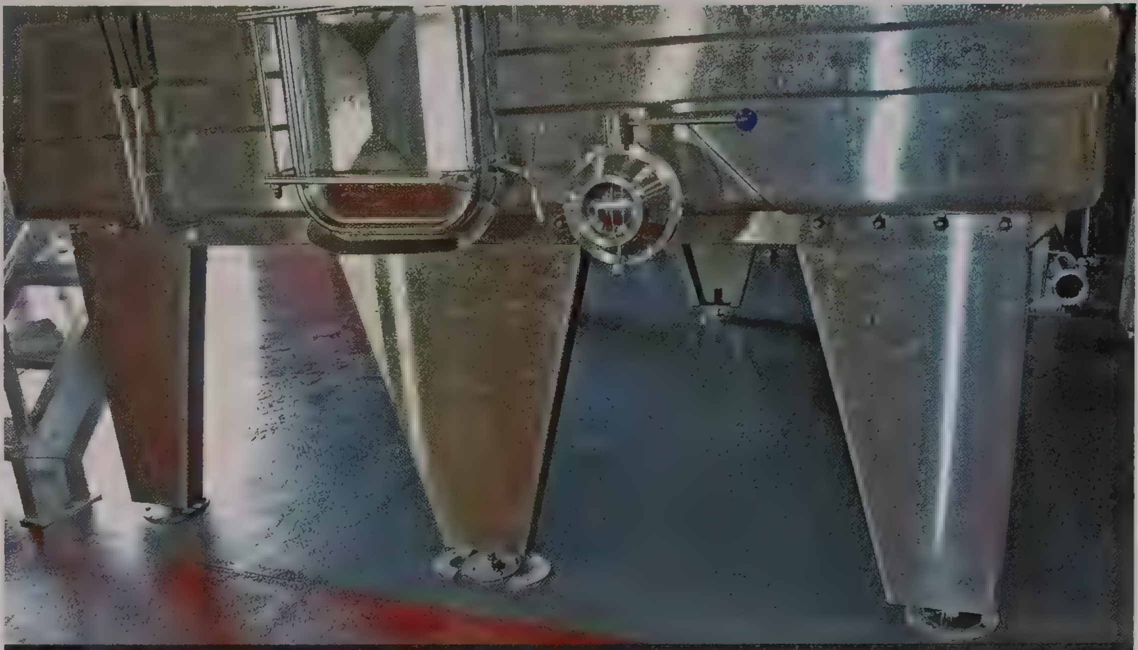
ing chilled glycol supply and return solenoid valves.

In this system's design, a special upper jacket solenoid valve was incorporated to allow flow to the upper cooling jacket only in the cooling mode to cool the cap during fermentation. This is a concept that has been incorporated on many new tank additions at Rodney Strong Vineyards that have a warming feature.

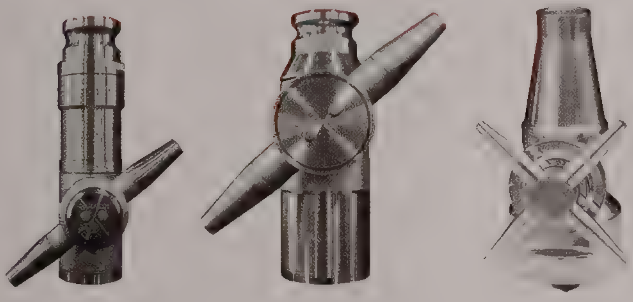
During the warming mode, the TankNet controller activates warm glycol supply and return solenoid valves but with the upper jacket cooling solenoid valve remaining closed, supplying warm glycol to the lower jacket only.

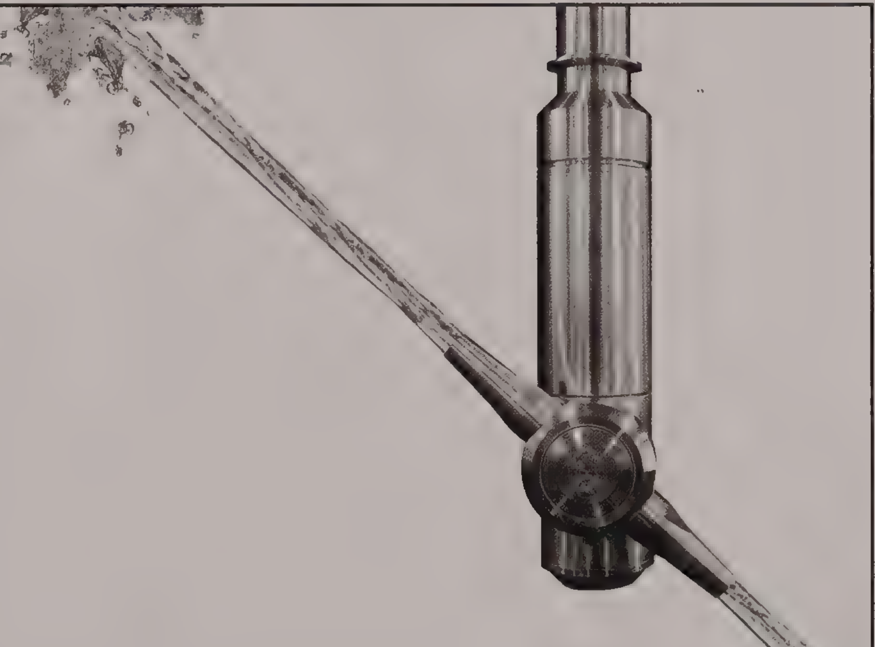
"Three additional special features were included in this installation to guard against line breaks and loss of glycol," adds Heasell:

- Flex connectors were installed in the glycol piping at the tank jackets to compensate for pipe and equipment movement caused by catwalk movement, tank wall movement or even mild earthquakes. During the August 2014 earthquake near Napa, Calif., numerous wineries experienced cracked piping and loss of propylene glycol solution. Installation of flex connectors in the glycol piping should help in this regard.
- A glycol line pressure transducer was installed. Upon a loss of glycol pressure, a PLC is specially programmed to deactivate the glycol pumps and make an automatic notification.
- The piping and valve assemblies were arranged to take advantage of the work space. Facilities manager Larry Solomon, along with APCCO and other contractors, designed the piping layout between the backs of the tanks by holding the assemblies close to the tank wall (see photo on page 12). In addition to providing valuable hose and pump storage space, this allows for cellar and maintenance personnel to easily and quickly approach and isolate the valves manually in an emergency. It also provides the working space needed by service crews to replace/repair valves and fittings as quickly and efficiently as possible.



Anchor-collars surround tank feet to minimize seismic movement in an earthquake.





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Cap management in primary fermentation

"For grapes fermented in the new cellar, our cap-management program allows for changes based on many different factors with some basic guidelines," says winemaker Justin Seidenfeld.

Upon arrival at the winery of the hand-harvested grapes from the vineyard in the early afternoon, grapes are destemmed and receive an SO_2 addition with a target of 30 to 40 ppm total SO_2 in tank.

On day two, a sample is taken for juice analysis. On day three, initial nutrients are added and either the fermentation is allowed to start without inoculation or U43 yeast is added, based on winemaker discretion.

When fermentation has started, until about 10° Brix, there are three pump overs per day. Each pump over should turn over the tank volume once. From 10° Brix onward, there will be two pump overs per day (to turn over the tank volume one time). When the wine has fermented to dryness, there is one pump over per day to wet the cap, turning over between one-quarter and one-half of the volume during the pump over.

There are a few different parameters for temperature, but the goal is to allow the temperature to increase gradually. "We want to avoid spikes in the fermentation curve," adds Seidenfeld, "and use tank-wall refrigeration to guide the fermentation to a nice curve, with peak temperature between 75° and 85° F.

"When the wine reaches 0° Brix, we will use warm glycol in the tank wall to assist thermal maceration for additional extraction. We will warm the tank over several days from 84° to 88° F.

"Our goal is to have a minimum of 21 days of skin contact. We will make all pressing decisions based on taste and start daily tastings as soon as the wine in the tank is dry."

The free-run wine is drained from the fermentor to another tank for 24 hours of settling, and racked to another tank for inoculation with malolactic bacteria. The next day the inoculated wine goes to barrel with a Guth tank mixer stirring the lees during barrel-down.

Floor coating of new fermentation cellar

"Seidenfeld invested much attention on a state-of-the-art tank room expansion and found he had to solve durability and aesthetic issues with the existing floor of a cellar to be remodeled," says David Genova, Lennova VP of Operations.

Seidenfeld searched for a new flooring company that could solve technical drainage and durability issues. He learned about Lennova from colleagues at other wineries. "Seidenfeld asked to see if Lennova's approach of creating custom solutions and attention to detail could really meet Rodney Strong's needs," adds Genova.

"Rodney Strong and other wineries have found that natural compounds in wine such as sugar and acidity can seep through and both degrade and destabilize concrete floors. This creates a challenge as forklifts with a four-barrel pallet negotiate tank rooms with eroded, uneven and rutted floors. The damaged floors sometimes led to incidents impacting productivity, product loss and health code violations."

Seidenfeld reviewed a solution for eroded concrete floors at another winery's tank room. "Although he was pleased with the workmanship and performance of the flooring installed, he wanted to make sure that the solution would be a seamless flooring system that met the Rodney Strong Vineyards' unique needs and aesthetic values."

One big challenge for the new tank room was drainage. Lennova had to deal with existing elevations, newly installed trench drains and flat concrete with existing door openings to the building.

"Using a simple but effective method of long, straight boards, shims and levels we determined the appropriate deflection (drainage slope of 4 inches over 16 feet) for proper drainage. We used a material unaffected by fluctuating moisture and acidity that would also stand up to forklift traffic to build the needed deflection."

A resinous material was chosen with an anti-microbial additive to prevent bacterial growth rather than cement because most cement-based products lose tensile strength and impact resistance as it tapers to less than ¼-inch thick to accommodate the slope. The sloping material was mixed in manageable quantities and troweled in place over the existing concrete with the use of screed bars and forms (see photo on page 14).

A red and brown blend of decorative colored quartz was chosen for high traffic areas and charcoal gray for underneath the tanks.

"The fluid-applied, seamless flooring material has the viscosity/consistency of a pancake batter, and once the flooring is troweled in place and is leveled out over the sloping material, we broadcast the first layer of colored quartz," explains Genova. After curing and sweeping off the spent quartz, a clear build coat was applied, and the second layer of colored quartz was broadcast to ensure color uniformity and consistency.

Once cured, a clear seal coat was applied to lock in the colored quartz and begin the process of traction control. After the clear seal coat was cured, the entire flooring surface was protected with a clear, chemical-resistant and high-traffic sealer. Since this is a seamless floor application, the color separation actually doubled the time required for installation, as one color has to be completely dry prior to installing the other color.

The correct size of coarse aggregate was blended in and applied in the finish coats at a particular thickness to achieve the perfect balance between floor traction and ease of surface cleaning. The entire process from start to finish took approximately 28 working days completing approximately 11,520 square feet and 404 linear feet of integral cove base on the walls (12 inches high).

Installation of sloped floor.

Tank floor has a 4-inch slope from the wall to the floor drain between two rows of tanks.

By drawing on lessons learned from 15 years of customer experience, Lennova provided a unique solution for Rodney Strong Vineyards.

Barrel selections for new red wine blend

Seidenfeld has identified Cooperages 1912, Gamba and Vicard Generation 7 as the three primary cooperages for the new red wine blend.

Botti Generazioni, an extension of the Gamba Cooperage in the Piedmonte province of northern Italy, supplied barrels with a blend of 28-month naturally seasoned staves from the center of France that utilized a proprietary, slow Toast Check process.

Cooperages 1912 supplied three French oak barrels, each contributing a unique influence: World Cooperage Profile 8 for added spice, World Cooperage Profile 14 to enhance structure and the T.W. Boswell Legacy barrel for beautiful balance.

Vicard Generation 7 French oak barrels are coopered from staves with low, high and mixed tannin potential levels, and then "cooked" for 90 minutes with a patented bending and toasting process.

Luis Flores, barrel foreman, racks wine from tank into barrels while Justin Seidenfeld (right) samples barreled wine. Wine from the tank flows through a 3-inch diameter Waukesha variable speed 0 to 130 gpm positive displacement pump with a winged rotor. Four-barrel pallets are used at Rodney Strong Vineyard for best stability in an earthquake.

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Water conservation/sanitation in tank cellar

"A winery that has good sanitation standards produces wines that reflect that," says cellarmaster Manuel Villanueva. "A high-quality wine is difficult to achieve if you have poor sanitation practices. Rodney Strong Vineyards has been ensuring sanitation is a top priority for many years, but we need to find ways to continually improve.

"We have a four-step sanitation cycle that consists of: 1) warm water (85° to 100° F) rinse to remove debris and some organic stains, 2) caustic circulation to completely remove all organic stains and film residues, 3) cold water rinse to remove dirty caustic water, and 4) peracetic acid (PAA) circulation to kill any microorganisms remaining that the caustic solution missed.

"Approximately 50 gallons are used in each step. Depending on how dirty a tank is, we circulate the caustic solution for about 20 minutes and about 10 minutes circulation for PAA. We use a 10 hp centrifugal pump and a Lechler M20 sprayer on a cart on the tank floor.

"The pH level of the wash solutions are monitored to ensure the caustic wash is maintained above 10 to 11 pH and PAA wash is maintained around 120 to 140 ppm. When we dissolve the caustic solution in warm (85° to 100° F) water, we make sure the pH of that solution is above 10 pH using test strips or a digital pH pen. The PAA is tested with a test kit that uses a series of solutions (50% sulfuric acid, potassium iodide, starch indicator and sodium thiosulfate 0.1N/ peracetic DT) measured in drops to determine ppm.

A previous seven-step cycle took approximately 80 minutes and required approximately 1,000 to 1,200 gallons of water per tank sanitation. The four-step cycle has reduced the wash-time to approximately 30 to 45 minutes, and approximately 150 to 200 gallons of water are used.

"This change, along with reducing the water supply hose from 1-inch to ¾-inch diameter, has helped conserve about 1,000 gallons water per tank wash," adds Villanueva.

"To further conserve water, we will take the added step to collect and re-use the caustic and PAA wash water after cleaning a tank if the concentrations are at required levels and the water is not too visibly dirty. The PAA circulation in the tank is not rinsed so that the PAA can conserve the sanitized tank status longer. As long as we ensure the ppm are within tolerances and allow the tank to drain out all the water that settles inside the tank, direct wine contact to the tank is safe and has no harmful effect on the wine.

"We have swab-tested both methods of sanitation and found that although both consistently passed, the four-step method had passed in almost all areas that we swabbed (valves, gaskets, welds and inside tank top). We are experimenting with the new square tanks to see if we can achieve the same results without using caustic cleaner. Since the tanks have a special polished surface inside that reduces the pore size of the metal, they are more resistant to staining than non-polished tanks." PWV

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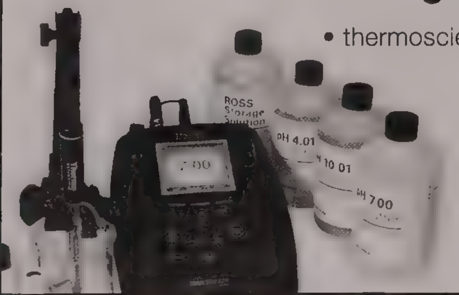

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TANNIN
Impacts and opportunities along the value chain

Studying tannins is challenging. Their behavior is rarely predictable; results can be contradictory, and experiments often seem to generate just as many questions as they answer. But if you step back and take a broader view of the tannin research conducted in the past few years, you can see that real progress has been made in understanding tannin at key points across the grape and wine value chain, with practical outcomes for growers and winemakers.

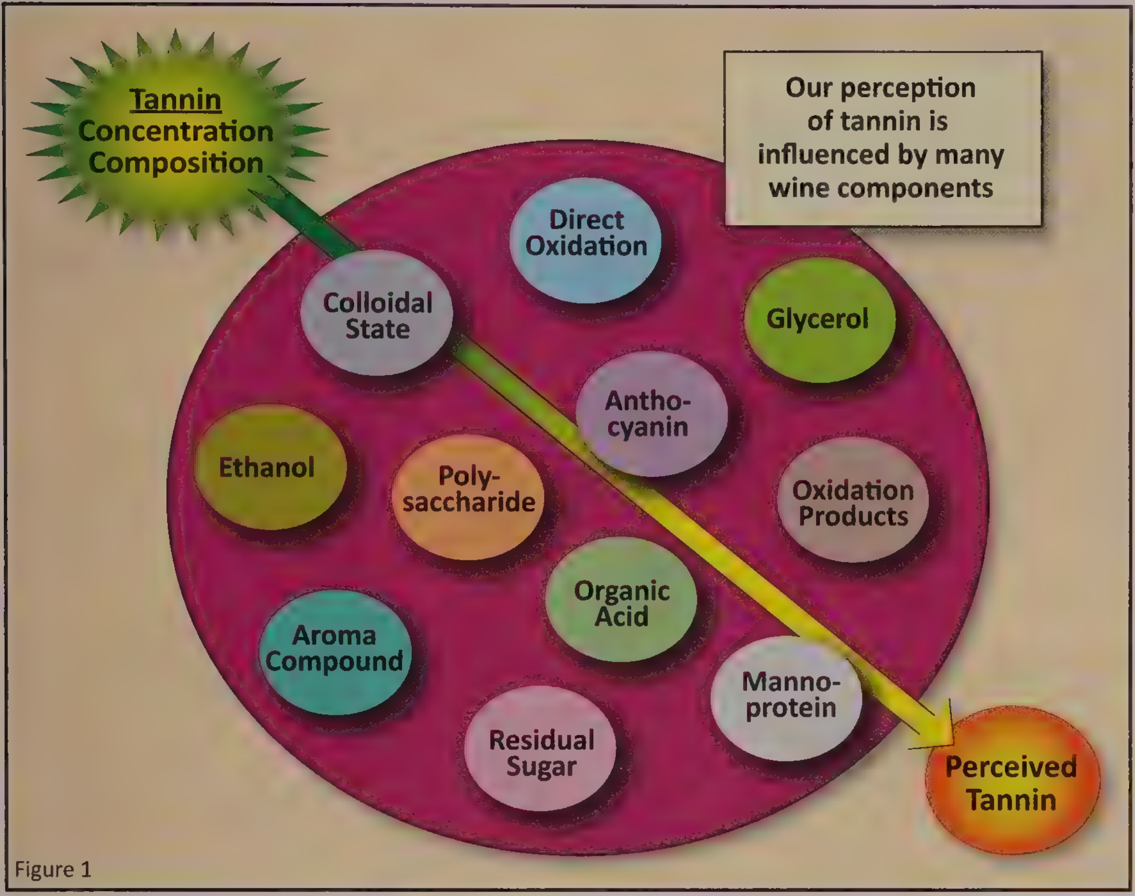

Figure 1

FIGURE COURTESY OF JAMES A. KENNEDY

BY Paul Smith, Keren Bindon, Jacqui McRae, Stella Kassara and **Dan Johnson**, Australian Wine Research Institute

Wine tannin originates from the tannin present in grapes; however the journey from grape tannin to wine tannin is not a straightforward one. Grape tannin needs to be extracted from solid grape material into must during fermentation, and then undergo chemical rearrangements to reach its final wine tannin form. This is why it is not a simple task to predict eventual wine tannin by measuring grape tannin— something winemakers would like to be able to do.

Understanding extractability

The extractablity step in the process – getting the tannins out of the grape solid material and into must— has been investigated, with a focus on the role played by grape cell walls.[1,2,3,4]

A number of factors were discovered that influence how easily tannin is extracted:

- Skin and seed tannins were found to interact with grape cell wall material, and this interaction limited the amount of tannin extracted during fermentation.
- Cell wall material interacted more strongly with seed tannin than skin tannin, most likely due to differences in their structure.
- Suspended flesh (pulp) material was shown to bind and remove tannin as lees during settling, after the tannin had been extracted during fermentation.
- Grapes with a low overall tannin concentration and grapes with a higher seed-to-skin tannin ratio were more affected by this removal of tannin by pulp.
- Seed tannin was shown to be less extractable than skin tannin during fermentation, but this varied significantly between seasons.

Influence of grape maturity

The effects of grape ripening on factors affecting extractability also were investigated.[5] Riper grapes were associated with:

- increased total skin tannin concentration, which could lead to higher wine
- more cell wall porosity which can result in a greater amount of total skin tannin trapped in the pores;
- more anthocyanin, which appears to enable extraction of tannin;
- more sugar leading to higher ethanol level, which may increase tannin and color extraction.

Results from these studies of extractability have highlighted the role of cell wall material in influencing tannin concentration during fermentation. The new understanding gained could lead to the development of methods to predict the extractability of tannin for a particular batch of grapes.

WINEMAKING

Influence of oxygen on wine tannin and color

As soon as grapes are crushed, chemical reactions start taking place that continue through fermentation and *élevage* and post-bottling maturation that eventually determine the wine's final color and taste. One key example is the reactions that convert grape tannins into more complex wine tannins. Oxygen has long been known to modify the astringency of red wines, but the chemical basis of this observation was unclear.

Winemaking experiments were conducted to investigate what happened when air was injected into red wine fermentations. Results showed important impacts of air additions on tannin concentration and chemical structure, with accompanying sensory effects. In particular, air reduced the concentration and

AT A GLANCE

Recent tannin research has delivered:

- Simple measurement of tannin and color in grapes and wine.
- Breakthroughs in understanding the extraction of grape tannin during fermentation.
- Knowledge about the influence of grape maturity on eventual wine color and tannin.
- Practical winemaking techniques that can be used to manipulate tannin.
- New understanding of what happens to tannin as wine ages and the importance of tannin structure for sensory properties.
- Insights into factors influencing color stability.

size of tannins, increased stable color formation and reduced the astringency of the wines compared with wines not treated with air.[10] This new knowledge provides practical options for winemakers to influence tannins during fermentation.

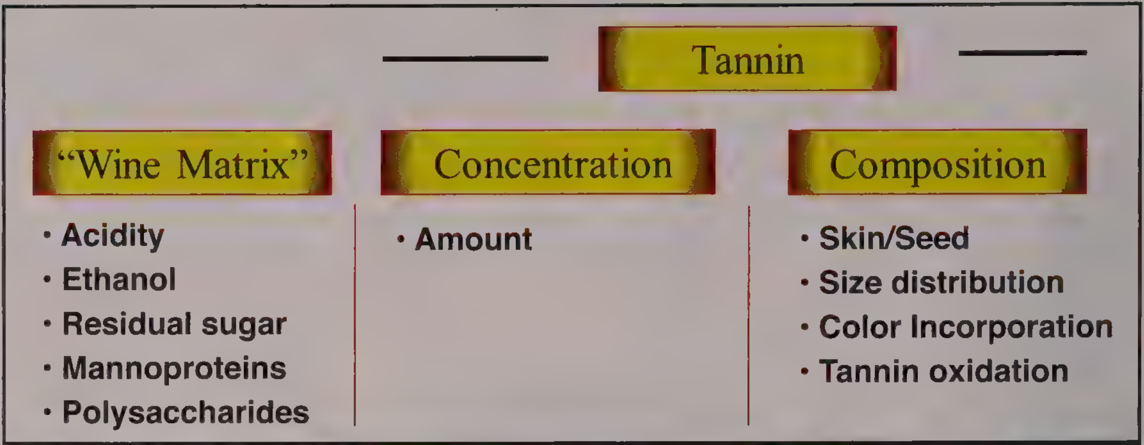

Figure 2. The management of wine mouthfeel can be separated into three broad categories including matrix elements, tannin concentration, and tannin composition.

FIGURE COURTESY OF JAMES A. KENNEDY

Impact of novel yeasts on tannins to improve wine quality

Yeasts are well known to influence wine aroma, but their effect on macromolecules and texture has been less well explored. A selection of yeasts were investigated for their effects on color and tannin and were shown to influence final tannin concentration by up to 50%, and to also significantly affect wine color.[20]

Further studies that evaluated the impacts of fermenting Shiraz and Pinot Noir with different yeast strains again showed a strong influence of yeast strain on tannin concentration.[9,11] For example, in experiments with Shiraz and Cabernet Sauvignon, wines made with *S. bayanus* strain 1375 and *S. bayanus* AWRI 1176 (Australian Wine Research Institute) had consistently low tannin concentrations whereas wines made with *S. cerevisiae* AWRI 1486 had generally high tannin concentrations. With all strains, the tannins in the wines were highly pigmented. This work demonstrates that the color and texture of red wines can be significantly modulated by choice of commercially available wine yeast.

Tannin measurement now widely available

In the past, lack of accessibility of methods to measure tannin has been a barrier for winemakers in optimizing wine tannin and color. Development of the simplified methlycellulose precipitation (MCP) tannin assay was the first step in breaking down that barrier. This method is published in the widely used *Chemical Analysis of Grapes and Wine; Techniques and Concepts* handbook by P. Iland *et al.*,[12] along with data from the Australian wine tannin survey, which communicates what can be considered low, medium and high tannin concentrations. An even simpler option is the web-based tool offered by the AWRI that allows producers to measure and benchmark tannin and color in both grapes and wine. This tool forms a component of the WineCloud.

Investigation of compounds with sensory impact

The importance of the structure of red wine tannin in influencing wine mouthfeel has been investigated.[18] The study showed that larger and more water-soluble wine tannins are more astringent, while smaller wine tannins that are less water-soluble, have more color and more oxidative structures were perceived as hotter, more bitter and less astringent. These results demonstrate that different types of tannins can influence mouthfeel and confirmed that modifying wine tannin structures during winemaking is a practical path to altering wine mouthfeel.

ÉLEVAGE

Color development and stability

During red wine *élevage* and post-bottling maturation, winemakers hope for the formation of long-term stable, red color. Yet in some situations, color is inadequate from the beginning or is unstable and fades fast. While some of the factors influencing stable color formation are known, others remain a mystery.

One of the main reasons for the color change seen in wine during *élevage* and post-bottling maturation is the decrease in anthocyanins (red pigments derived from grapes) and changes to pigmented tannins (stable colored compounds formed by reactions between anthocyanins and tannins).

Analysis of 30- and 50-year vertical series of Cabernet Sauvignon and Shiraz wines showed that wine color density was more strongly associated with pigmented tannins over the 30- and 50-year series than with anthocyanins (after the first two years post-bottling), clearly reinforcing the importance of pigmented tannins to wine color. In general, after four years no colored anthocyanins were left in red wine.[16]

In a separate experiment, wine color density was tracked through three years of maturation in wines of both high phenolic potential (high anthocyanin, high tannin) and low phenolic potential (low anthocyanin, low tannin).[6] Higher wine tannin and anthocyanin led to enhanced wine color density and stable non-bleachable pigments, which were retained through maturation. Formation of non-bleachable pigments was found not to increase beyond two years of maturation.

The incorporation of color during fermentation through to post-bottling maturation was proportional to tannin concentration. Non-bleachable pigments were formed via multiple routes, such that high-tannin, high-anthocyanin wines formed greater quantities of both polymeric and non-polymeric red pigments. Further work is required to understand how these alternative mechanisms for stable pigment formation can be harnessed.

To summarize, low tannin concentration does not necessarily prevent the formation of stable non-bleachable pigments, but high tannin concentration maximizes the likelihood of long-term color stability.

Astringency changes

Analysis of the vertical series also clearly indicates that aged red wines can have similar tannin concentrations to young wines, dispelling the commonly held belief that changes in red wine astringency with post-bottling maturation are due to the loss of wine tannins through precipitation. Such changes in astringency are instead due to compositional changes in tannins, although the rate of these changes is unknown.

The structure of tannins isolated from older wines were analysed to try to understand the changes observed in astringency as wines age.[15] The "aged wine tannins" were shown to only weakly associate with saliva-like proteins compared to tannins from younger wines. This is consistent with observed lower astringency of old wines, as the sensation of astringency is linked with strong association between tannins and salivary proteins.

In addition, the analysis revealed a large proportion of tannin that cannot be broken apart (tannin that is

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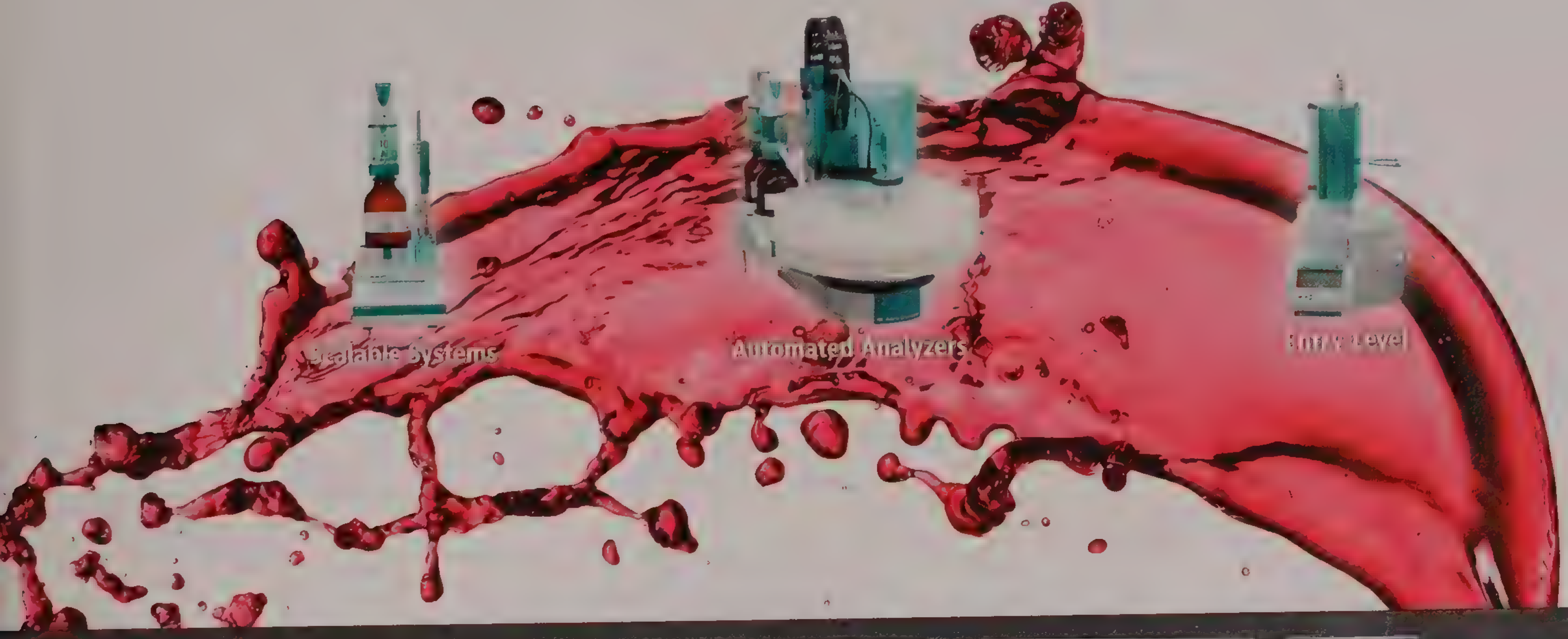

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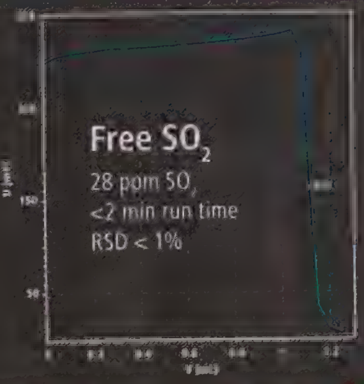

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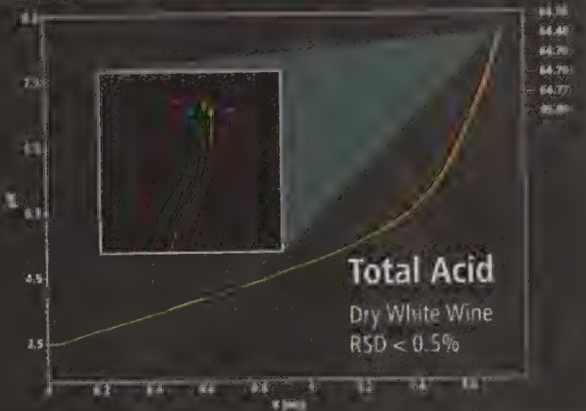

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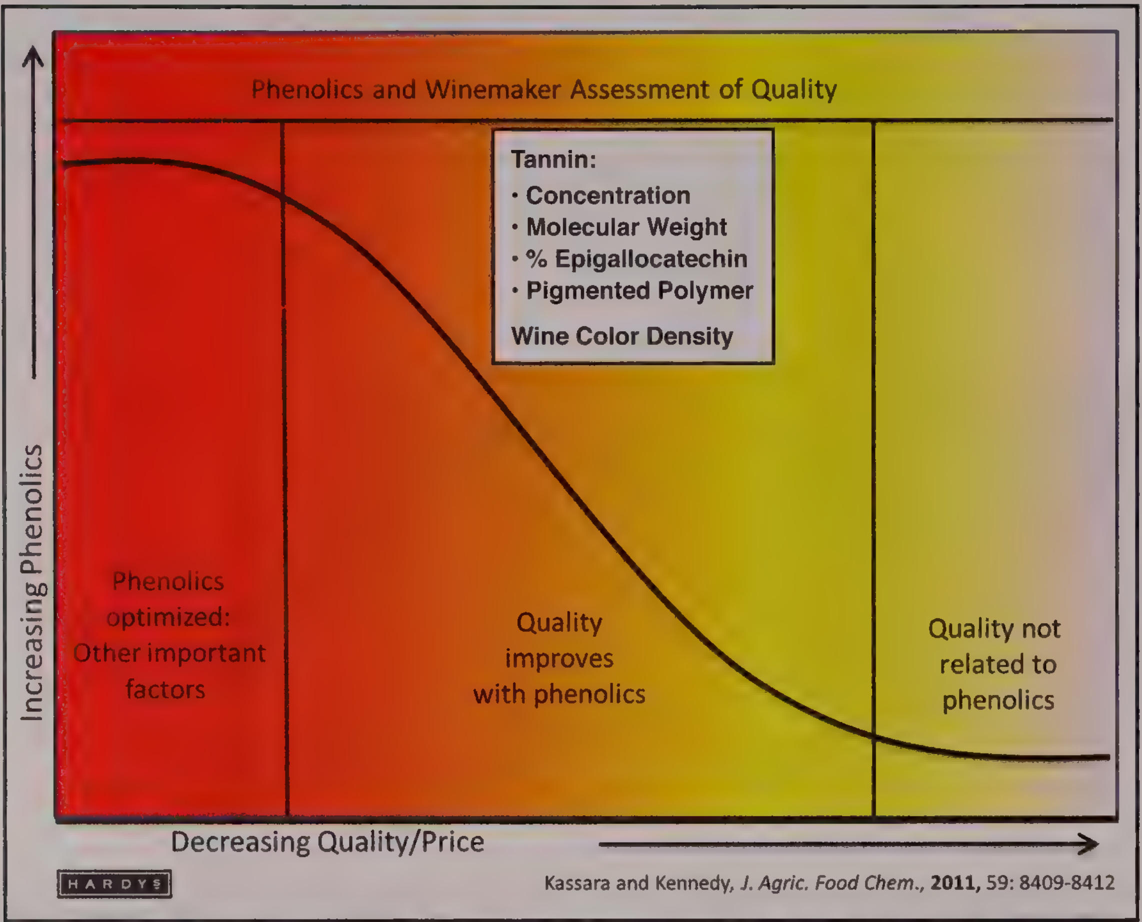

Kassara and Kennedy, *J. Agric. Food Chem.*, **2011**, 59: 8409-8412

FIGURE COURTESY OF JAMES A. KENNEDY

Figure 3. Results from the analysis of a large set of wines and comparison with winemaker assessment of overall wine quality indicates that overall wine quality is related to phenolics over a large portion of the wine quality spectrum.

non-hydrolysable), unlike grape tannin, which is readily broken apart. This non-hydrolysable proportion of wine tannin has also been shown to have a very weak association with saliva-like proteins and accounts for a larger proportion of aged wine tannins than young wine tannins. These results may, at least in part, explain why red wines "soften" with age.

An additional experiment demonstrated that tannin structure in Shiraz wines is not influenced by storage at different pH levels (3.2, 3.5 and 3.8) or under different screwcap closures with specific oxygen-transfer rates after two years of bottle storage, even though wines of lower pH are often reported as more astringent.[17] This suggests that a lower pH has a direct effect on sensory perception of the wine examined, but does not necessarily influence wine tannin evolution. These results provide improved insight into the stability of tannins in wine and underscore the importance of wine matrix influences on perceived mouthfeel.

Overall, astringency has been demonstrated to depend on the type of tannin and not just the amount present. In the future by targeting the creation and retention of specific types of tannins, it should be possible to create wines that have the softer mouthfeel of an aged wine, but at a much younger age.

CONSUMER

Higher tannin does not always mean more consumer preference

A trial was conducted where Cabernet Sauvignon wines were produced from grapes from the same vineyard harvested at five different maturity stages. The wines were found to have significant differences in tannin and color, with lower alcohol (12%) wines having lower tannin, a lower proportion of skin to seed tannin and less color and polymeric pigment compared to higher-alcohol wines (15%).[7]

Astringency increases were correlated with higher tannin for later harvested wines.[8] In the experiment, the five wines were presented to a group of consumers who rated how much they preferred the different wines. Results showed that wines of 13% alcohol or higher were preferred compared to lower alcohol wines. However, no further increases in consumer preference were observed for the wines between 13% and 15% alcohol, despite increases in tannin.

Importance of tannin structure on wine quality

There continues to be demand from industry for understanding as to how wine tannin composition (not just concentration) influences quality, wine grading or price, and research has addressed the role of tannins in the quality/grading/price nexus.[19]

Quality (defined as winemaker-assessed grading that ultimately relates to market price) in young red wine was positively correlated with tannin concentration, tannin size, higher proportion of skin-derived tannins and overall wine color (see Figure 3).[13,14] This suggests that maximizing skin tannin concentrations and/or proportions in wines can contribute to an increase in projected wine bottle price, but this must be done in balance with other wine components which contribute to the desired wine style. Management factors associated with increased skin tannin concentrations include:

- reduced vine vigor and vine water status,
- increased fruit exposure,
- increased berry crushing prior to fermentation, combined with reduced soak time,
- use of enzymes.

Conclusions

Effectively managing vineyards and winemaking to optimize grape and wine tannin and color translates into increased capacity for the Australian wine industry to meet wine specification, consumer expectations and profitability. Specific areas where winemakers can now take practical steps to influence wine tannin include:

- choice of yeast,
- management of oxygen during fermentation,
- viticultural and winemaking choices that aim to maximize proportions of skin tannin.

Tannin research at the AWRI has provided the Australian wine industry with an improved understanding of structures, measurement, formation and function of phenolics compounds responsible for wine texture and color, and it has significantly progressed the scientific framework for improvements in winemaking.

Several areas have been identified with potential to return high value and knowledge gaps for future research. In particular, the importance of understanding how tannins, proteins and polysaccharides work together in wine represents a research opportunity with significant potential to support production of desired wine styles. This work is continuing in Project 3.1.4 of the AWRI's R, D&E plan 2013–2018.

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Describing oral sensations elicited by white wine

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Wine is renowned and valued for the variety and complexity of sensations that it elicits, including visual (hue, intensity and clarity), olfactory (ortho- and retro-nasal aroma), taste (sourness, sweetness, bitterness and saltiness), and those associated with the chemesthesis and somatosensory systems. When activated by wine, the latter two systems contribute to what we experience as "tactile sensations" or mouthfeel, with polyphenolic compounds (tannins) recognized as one of the main elicitors in red wine.

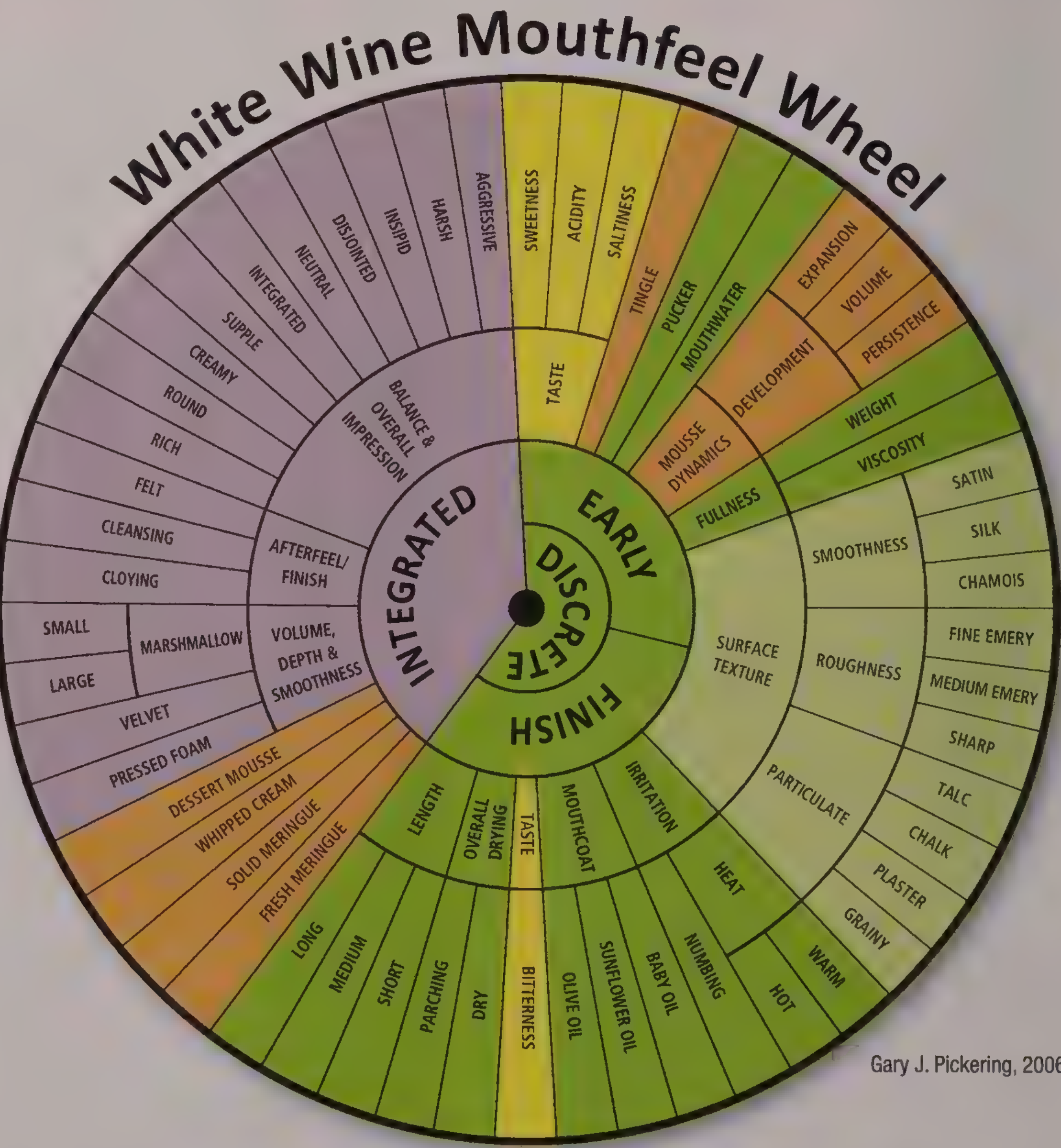
Mouthfeel is widely recognized as an important quality indicator for red wine and may be an important component of overall consumer appeal.[9] However, mouthfeel has not been well-studied, possibly due to the absence of a commonly accepted definition and difficulties in measuring the typically subtle sensations it encompasses.

R. Gawel *et al.* have developed a red wine "mouthfeel wheel" (RWMW)—a hierarchical lexicon designed to assist in identifying and classifying these complex oral sensations.[12] In addition, these authors identified reference standards that may be used for training judges to describe and measure individual mouthfeel attributes.

These standards are often fabrics, papers and other materials, assessed manually, that represent the oral equivalent of the sensation. As an aid to descriptive analysis panels, the RWMW has helped with measuring the impact of processing and compositional variables on the subtle mouthfeel characteristics elicited by actual and model red wines.[5,6,7,11,14,29,30,31]

White wine

White wine can elicit the basic tastes



Gary J. Pickering, 2006

Figure 1: White Wine Mouthfeel Wheel. Terms are categorized as DISCRETE or INTEGRATED (consisting of more than one sensation or concept). DISCRETE categories/sensations are ordered clockwise according to their approximate order of perception or maximum intensity. Outer-tier terms for Surface Texture, Irritation, Mouthcoat, Overall Drying and Length represent reference descriptors and/or standards for quantifying sensations. Color code: Brown = attributes predominantly elicited by sparkling wines; yellow = Taste qualities; deep green = Non-Taste sensations; light green = Surface Texture attributes; purple = INTEGRATED qualities.
Copies of this wheel and related resources can be purchased from mouthfeelwheel.com.

"At a glance"

White wines can elicit a wide range of taste and mouthfeel sensations, some of which may be qualitatively different to those elicited by red wine. Through extensive sensory panel work involving 136 wines and 21 sessions, a lexicon, set of definitions, evaluation protocol, and reference standards have been developed to describe and measure the oral sensations elicited by white wine, including table, sparkling, dessert, dealcoholized and fortified styles.

The lexicon is presented as a hierarchical wheel structure. These tools can be used to more fully define the influence of viticultural and enological variables on white wine quality and to aid in the training of and communication between wine professionals. The results of one such application of the mouthfeel wheel are summarized where lactic acid bacteria strains were shown to influence the texture of Chardonnay wines in different ways.

of sourness, sweetness, bitterness and saltiness. In addition, a number of components have been shown to impart mouthfeel sensations, particularly those associated with "fullness," including glycerol, sugar and ethanol.[18,21]

Ethanol (alcohol), along with contributing to sweetness[1] and bitterness,[17] can also elicit tactile sensations, specifically heat/irritation[13] and astringent-like drying.[4,29]

Organic acids can elicit astringent-like sensations[25,27] and polysaccharides mediate the perception of astringency intensity.[31]

Polyphenolic constituents of white wine also elicit astringent sensations, although their concentration is significantly lower than in red wine.

Additionally, hydroxycinnamates, rather than flavonoids, make up the dominant species and significant cultivar differences are found.[15]

Thus, white wines also elicit a wide range of taste and mouthfeel sensations, some of which may be qualitatively different from those experienced in red wine. In addition, oral sensations such as astringency are clearly dynamic,[24] changing in intensity and perhaps quality while the wine is being evaluated. This time "dimension" for oral sensations is not incorporated in the RWMW.

These considerations were the catalyst for the study, which seeks to develop an appropriate and comprehensive vocabulary, system of classification and set of reference standards for the oral sensations elicited by white wine. This should help in developing a common understanding among wine tasters and winemakers of terms describing mouthfeel and other oral sensations and aid in communication of those descriptors.

Such a tool may also assist the research community by facilitating a more comprehensive and systematic evaluation of the effects of viticultural and enological treatments on mouthfeel and related sensations elicited by white wine.

Materials and methods

The sensory panel consisted of 11 individuals (eight females and three males, between ages 24 and 60). All were experienced wine tasters, including wine industry professionals (two winemakers, one sommelier and one wine writer) and senior staff and students from Brock University's Cool Climate Oenology & Viticulture Institute (CCOVI) and were recruited based on their experience, interest and availability.

Development of the white wine mouthfeel wheel occurred in 21 one-hour sessions in a panel discussion room and sensory evaluation lab at CCOVI. For all sessions, water and fresh bread were provided to cleanse the palate between wine samples, and nose clips were used to assist the panel in focusing on oral sensations and to remove the influence of olfactory cues.

Wines were presented in ISO tasting glasses and at serving temperatures appropriate for their style, ranging from approximately 7° to 16° C. In the first 11 sessions, the panel evaluated 77 white wines. These were representative of 12 Old and New World wine-producing nations and styles, and further selected to represent as wide a range of oral sensations and vintages (11) as possible.

Examples included 51 table, 11 sparkling, 9 dessert, 4 fortified and 2 reduced-alcohol wine styles. Sparkling wines included samples produced using *méthode classique, méthode champenoise, méthode cuvée close,* charmat method, natural fermentation, and Asti techniques.

During the first sessions, introductory exercises were conducted using eight aqueous solutions representing common oral sensations, to assist the panel in distinguishing between taste and tactile sensations. Attributes and solutions used were: carbon dioxide (mineral water),

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Table I: Definition, intensity terms, and reference standard used for outer-tier descriptors of discrete sensations

Outer-tier descriptors	Definition	Intensity terms / levels and scale anchor terms	Standard type
Sweetness	—	Low, medium, high	Oral
Acidity	Sourness	Levels 1–4	Oral
Saltiness	—	Low to moderate	—
Tingle	Sense of irritation usually associated with carbonation	Low to high	Oral
Pucker	Reflex action of mouth surfaces being brought together and released in an attempt to lubricate mouth surfaces[1]	Low to high	Conceptual (see definition)
Mouth-water	Reflex reaction characterized by excess production of saliva	Low to high	Conceptual (see definition)
Expansion	Rate of mousse evolution and de-evolution in the mouth	Evolution: slow to fast De-evolution: slow to fast	Conceptual (see definition)
Volume	Sense of fullness created by mousse in the mouth	Low to high	Conceptual (see definition)
Persistence	How long mousse is retained in the mouth	Short to long	Conceptual (see definition)
Weight	Sensation of 'body' when the wine is stationary in the mouth	Light to heavy	Oral
Viscosity	Varying degrees of viscosity from thin to thick	Thin to thick	Oral
Warm and hot	Differing intensity of heat sensation	Warm to hot	Oral
Silk, satin, and chamois	Surface texture of varying degrees of softness / smoothness	Low / light (satin) Moderate (silk) High / heavy (chamois)	Manual
Fine emery, medium emery, and sharp	Increasing degree of roughness in surface texture	Low (fine emery) Moderate (medium emery) High (sharp)	Manual
Talc, chalky, plaster, and grainy	Particulate sensations ranging from fine to coarse particles	Fine (talc) to coarse (grainy)	Manual
Numbing	Loss of sensation in the mouth	Low, moderate, and high	Conceptual (see definition)
Baby oil, sunflower oil, and olive oil	Mouth-coat sensation	Light (baby oil) Moderate (sunflower oil) Heavy (olive oil)	Manual
Bitterness	—	Low, moderate and high	Oral
Dry and parching	Overall drying sensation as experienced by loss of moisture in the mouth. Parching refers to the excess removal of moisture from the mouth.	Low, medium, high, parching	Oral
Short, medium, and long	Persistence of any oral sensation	Short, medium and long	Conceptual (see definition)

[1] From Gawel *et al.* (2001)

sweet (10 g/l sucrose), acid (2.5 g/l tartaric acid), hot (15% v/v ethanol), astringent 1 (2 g/l alum sulphate), astringent 2 (1 g/l grape seed tannin), viscous (2 g/l carboxymethyl cellulose) and bitter (0.1 g/l quinine sulphate).

In the first 11 sessions, descriptive analysis and focus group techniques were used to generate appropriate descriptive terms to describe oral sensations elicited by the wines. Between five to eight samples were presented at any one session, with wines of similar style presented together according to the following general groupings: Chardonnay, sparkling, late harvest and sweet, high acid, other table wines, low alcohol and fortified.

Panel members were instructed to take each wine into the mouth, swirl it from side to side, and expectorate. After expectoration, they were asked to move their tongue around their palate, and complete the process of generating as many descriptors as they felt appropriate to describe the oral sensations experienced.

The RWMW was provided to the panel as a guide for possible descriptors.[12] After each wine, the panel discussed their experiences and assisted in the process of organizing and rationalizing the developing lexicon.

After all wines had been evaluated once, candidate descriptors for the final lexicon were limited to those used more than four times and by more than one panelist across all samples presented. The descriptor generation sheet was divided into six sections to capture information on how the sensations changed with time. Specifically, "initial" (0 to 3 seconds after ingestion), "in mouth" (3 to 18 seconds), "at expectoration" (18 to 23 seconds), "finish—early", "finish—mid," and "finish—late."

A sub-set of 35 representative wines was presented in seven sessions to assist in fine-tuning the developing lexicon, definition sheet, and reference standards. After extensive panel discussion, the descriptive terms were categorized into sensations that could be conceptualized as having one clear intensity component and those that were an amalgam of more than one sensation or concept.

These attributes were sub-categorized according to the type of sensation (such as taste or surface texture) and the time when they reached their peak intensity, and then represented in a hierarchical wheel structure after R. Gawel *et al.'s* mouthfeel wheel.[12] To aid in the utility of the lexicon and wheel, the original six time-categories were reduced to two (early and finish) by panel consensus.

In developing the lexicon, oral and manual reference standards were developed, refined and used extensively by the panel to represent the sensations and their perceived intensity and to minimize ambiguity in use of descriptors. For terms where physical standards could not be developed, conceptual definitions were derived by panel consensus.

In the last four sessions, 24 representative wines were presented to the trained

Table II: Composition of oral and manual reference standards and their application for discrete sensations

Outer-tier descriptors	Final composition of standards	Evaluation protocol
Sweetness	30 g/L sucrose (Sigma-Aldrich) in water (corresponds to anchor term sweetness at 2.5 cm)	Swirl sample around mouth
Acidity	1,2,3 and 4 g/L of tartaric acid (Fischer™) in aqueous solution (corresponds to "*Levels 1,2,3 and 4*", respectively)	Swirl sample around mouth
Saltiness	*Moderate* = 1.5 g/L NaCl in aqueous solution	Swirl sample around mouth
Tingle	*'Slight'* = Moderately carbonated mineral water (bottle cap partially unscrewed for 24 hrs to release some CO_2) *'Tingle'* = Moderately carbonated mineral water opened immediately prior to serving	Swirl sample around mouth
Weight	a concentration series of 0.5 g/L, (*'light'*), 1 g/L (*'moderate'*) and 2 g/L (*'heavy'*) of carboxymethyl cellulose (Sigma-Aldrich) in aqueous solution	Take equal volume of sample and hold in mouth
Viscosity	a concentration series of 0 g/L (*'thin'*), 0.5 g/L, 1 g/L, 2 g/L, and 3 g/L (*'thick'*) of carboxymethyl cellulose (Sigma-Aldrich) in aqueous solution	Take equal volume of sample and move from side to side in mouth
Warm and hot	*Warm*: 13% v/v ethanol (LCBO, Canada) solution *Hot*: 15% v/v ethanol (LCBO, Canada) solution	Swirl sample around mouth
Silk, satin, and chamois	2 x 3.5 cm strips of silk fabric, satin fabric, and chamois cloth (all Fabricland™, St Catharines)	*Silk:* rub the bottom 'shiny' side of the fabric between your forefinger and thumb moving with the nap; *Satin:* rub with your thumb the shiny 'top' side of the fabric moving with the nap; *Chamois*: rub the smoother side of the cloth between your forefinger and thumb
Fine and medium emery	2 x 3.5 cm strips of fine and medium emery paper (respectively, 600 grit and 220 grit Norton® all purpose sandpaper, Home Dept™, St Catharines)	Hold the emery paper firmly between forefinger and thumb while rubbing the sample back and forth with thumb
Sharp	single sheet of heavily crinkled aluminium foil paper rolled into 3 cm diameter ball	Roll aluminium foil ball between the palms of your hands
Talc, chalky, plaster and grainy	Talc powder: Johnson and Johnson® baby powder Chalk: standard blackboard chalk Plaster: dry gypsum powder Grainy: sand from Vanwagners beach, Hamilton Ontario	Rub each standard between thumb and fingers
Baby oil, sunflower oil and olive oil	Baby oil (*'light'* mouthcoat): Johnson and Johnson® baby oil Sunflower oil (*'moderate'* mouthcoat): Unico® sunflower oil Olive oil (*' heavy'* mouthcoat): Bertoli® extra virgin olive oil	Insert finger in oil and smear between forefinger, middle finger and thumb in a circular motion
Bitterness	0.05g/L of quinine sulphate in aqueous solution = *moderate* bitterness intensity	Swirl sample around mouth
Dry and parching	A concentration series of 0.05 g/L, 0.1 g/L, 0.25 g/L and 0.5 g/L alum sulphate in aqueous solution, representing *low, medium, high,* and *parching* drying sensations, respectively	Swirl sample around mouth

panel to assess the utility and discriminatory properties of the wheel, and to make minor adjustments to definitions, standards and evaluation methods. Intensity scales were employed for discrete descriptors, while presence/absence ratings were used for integrated descriptive terms.

Results

Figure I shows the final lexicon, visualized as a hierarchical, segmented wheel (see page 22). The wheel is divided into 33 discrete sensations and 21 integrated percepts, consisting of more than one sensation or concept. Further ordering of the tiers is based on groupings of increasingly similar attributes, similar to the structuring used by R. Gawel *et al.*[12]

Outer-tier terms are the specific oral qualities that are used to score and describe white wine. Segments are color-coded to facilitate ease of use by grouping attributes together that belong to the same oral quality/ dimension or that are elicited by the same wine style.

Attributes that were predominantly elicited by sparkling wines are color-coded brown, and taste qualities are yellow. Non-taste sensations are deep green, while those that pertain to surface texture attributes are light green. Integrated qualities, other than those elicited by sparkling wines, are purple.

Table I lists outer-tier terms derived by the panel to describe discrete sensations, along with their definition, intensity terms and the type of reference standard used. Table II gives the composition of the oral and manual reference standards for discrete sensations and a description of how they are used or evaluated. Table III shows the same information for integrated sensations. Figure II provides representative examples of the scales derived for quantifying discrete oral sensations elicited by white wine.

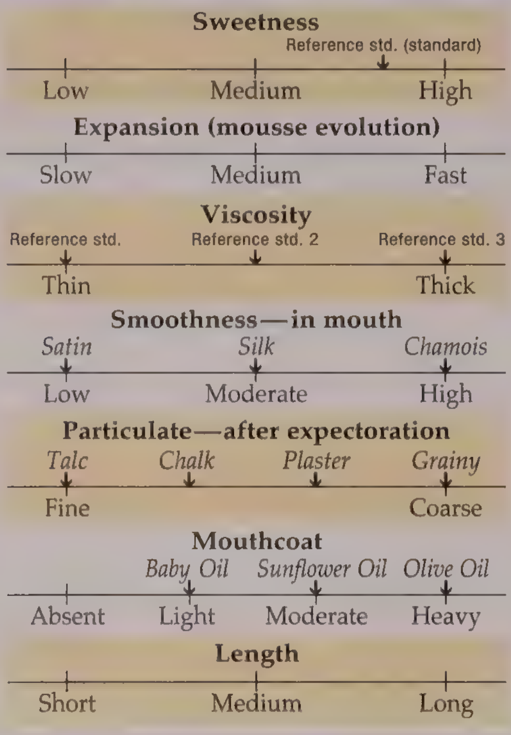
Discussion

In development of the RWMW, sorting tasks by the panel and subsequent cluster analysis were used to assist in categorization of astringency terms. This approach was not used in our study, assuming that the validity of the groupings developed by R. Gawel *et al.* would hold for white wine.[12]

Focus-group techniques were used extensively where the experienced panel played a dominant role in development and refinement of the terminology, categorization of the descriptors and development of reference standards.

There is significant overlap between the white and red wine mouthfeel wheel lexicons, definitions and grouping of sensations, which is to be expected given

Figure II: Representative scales used for measuring discrete oral sensations elicited by white wine



that the RWMW was used as a "starting point" in this study. However some significant differences are apparent and discussed below.

The clear division of the wheel into discrete and integrated sensations partially addresses concerns with the RWMW that some terms are compound in nature and/or contain a hedonic component, and perhaps confound a common understanding of some attributes. However, the lexicon is not free from this potential criticism, and further work is required to establish the reliability and descriptive value of the integrated descriptors.

Fresh meringue, solid meringue, whipped cream and dessert mousse, for example, may seem unusual terms to describe wine. The panel felt strongly that these products, when assessed orally, elicited very similar sensations to many sparkling wines with respect to the impression of fullness and dynamic feeling of expansion. Their actual utility in assisting with describing and discriminating sparkling wine remains to be determined.

The RWMW contains descriptors that normally carry flavor connotations (retronasal odor—such as pepper, chili or resinous), even though they are defined without reference to olfaction, and a "slice" of the wheel is dedicated solely to flavor attributes (lift, activity and concentration). We attempted to avoid descriptors related to flavor in order to simplify the task of the assessor(s) and develop a lexicon as focused and unambiguous as possible.

The ecological validity of using nose clips should be further investigated. For instance, how well do terms generated in the absence of olfactory cues describe the oral sensations experienced under normal wine evaluation conditions, and particularly the absence of nose clips?

Numerous interactions between aroma, taste and tactile sensations have been documented in the literature. For instance, taste may enhance aroma intensity or suppress it.[16,32] Conversely, aroma may enhance or suppress taste intensity.[8,28]

Mediating factors in the direction and extent of these interactions include prior association with the particular flavor-taste combination[28] and whether a "gestalt" or analytical paradigm is used to assess stimulant combinations.[22] Irritants have also been shown to interact with both taste and smell perception, for instance suppressing sweetness[23] and some odors.[2]

Studies have confirmed that tactile stimuli can also modify taste and aroma perception.[3] While the role of texture in controlling flavor release and thus aroma and taste intensities is significant and well-documented,[33] there is evidence that a perceptual integration of these modalities may also be involved.[34]

Much of the research investigating textural/tactile interactions with other sensory modes has been confined to solid and semi-solid foods/model foods or relatively simple food systems. However, given these previous findings, it is possible that aroma cues will influence perception of some mouthfeel attributes elicited by white wine, although recent work from our lab found no effect on the perceived astringency and bitterness of catechin from the addition of odorants [35]

Descriptors are ordered clockwise on the wheel, starting at "12 noon," according to the approximate order of perception or maximum intensity experienced. This should assist judges in finding and rating terms more easily, particularly important given the large number of descriptors presented here and when assessing complex wines eliciting multiple sensations.

In contrast with the use of the RWMW by R. Gawel *et al.*,[11,12] terms on the outer edge of the white wine wheel generally represent points on the scale for inner-tier sensations. The panel found this organization useful when conceptualizing mouthfeel attributes and in subsequent scoring of wine, as they were already familiar with the line-scale anchor terms and qualities to which they related.

Structuring of the wheel into two time components (early and finish) assists in more fully characterizing mouthfeel sensations, particularly given the known changes in intensity during evaluation of wine astringents.[10] The decision to reduce six original time-segments down to two was made primarily for pragmatic reasons, to increase the ease to use the wheel. However, more research is encouraged to fully define how oral sensations elicited by wine change in both quality and intensity over time.

Scales and data analysis

During preliminary trials using this wheel, the judges rated discrete sensations using traditional, 15 cm visual analog scales anchored with adjectives and, where appropriate, reference standards (Figure II). Data collected in this way can be assessed using powerful parametric statistical techniques such as analysis of variance. Additionally, multivariate methods such as principal components analysis can be applied, which allow for thorough exploration of the data, including defining of relationships between the descriptors.

Integrated terms are best rated as simply present or absent. The data can then be analyzed using a number of non-parametric options. Simply tabulating the frequency of use of each integrated term across the panel can provide valuable information of how wine samples differ for those attributes. Results for both discrete and integrated terms can be graphed using cobweb plots/radar graphs, which can provide an intuitive and clear presentation and description of each wine.

Visual analog scales used for discrete sensations are typically scored by having each judge place a vertical mark on the scale that corresponds to their perception of the intensity or quality of the attribute under consideration. The distance from the origin (left hand anchor mark) to their mark is then measured, and that distance (intensity score) is recorded.

The assessment is made relative to the reference standards and anchor terms, and the location of both on the scale can be altered depending on specific wines under examination.

For example, if a panel is evaluating heavily extracted or acidic wines that might elicit coarser sensations, the chalk standard can replace talc to anchor the left-hand end of the particulate scale (see Figure II), thus increasing the range of scale available that is appropriate to wines under consideration. This can increase the likelihood of establishing differences between samples.

In developing the lexicon, the panel rated some descriptors multiple times across different time-points. Particular sensations can be measured more than once during an evaluation to fully describe a sample, if needed. For exam-

Table III: Definition, reference standard composition and evaluation protocol used forouter-tier descriptors of integrated sensations

Outer-tier descriptors	Definition	Standard Type	Standard Composition and Evaluation Protocol
Fresh Meringue, Solid, Meringue, Whipped Cream and Dessert Mousse	A sensation of fullness and the dynamic feeling of exp ansion typically associated with sparkling wines	Oral	*Fresh Meringue:* beat the whites of 2-3 fresh eggs until stiff peaks form *Solid Meringue:* Presidents Choice meringue nests (Fortinos super market St Catharines) *Whipped Cream:* Cool Whip (Zehrmart Inc, St Catharines) *Dessert Mousse:* Fortinos supermarket (St Catharines) bakery mini chocolate mousse
Pressed Foam, Velvet, Small Marshmallow and **Large Marshmallow**	An overall sensation of smoothness, volume and depth. *Pressed foam, velvet, small marshmallow* and *large marshmallow* listed in increasing order of volume and fullness	Manual	*Pressed foam:* 3 cm width x 3 cm length x 0.3cm depth (Walmart, St Catharines) *Velvet*: 3 cm width x 3 cm length x 0.2 cm depth (Fabricland, St Catharines) *Small marshmallow:* 2 cm x 2 cm x 2 cm (No Name brand, Zehrmart Inc, St Catharines) *Large marshmallow*: 4 cm x 4 cm x 4 cm (No Name brand, Zehrmart Inc, St Catharines) *Foam*: assess using finger and thumb; push along the foam gently while stroking at the same time; *Velvet*: stroke with nap while wiggling the abric around between forefinger and thumb; *Marshmallows*: apply gentle pressure all over while moving marshmallow around hand
Cloying	High sweetness with a thick and persistent sensation experienced in the back of the throat	Oral	Koolaid jammers fruit punch (Fortinos supermarket, St Catharines)
Cleansing	An overall clean, refreshing sensation on the finish of the palate	Oral	lemon water standard (1 lemon quartered and combined with 1 L of Brita-filtered water and steeped for 10 min)
Felt	Refers to an overall sensation of roughness and drying in the mouth	Manual	3cm wide x 3.5 cm long x 0.2 cm deep strip of felt (Walmart, St Catharines) Rub between forefinger and thumb
Rich	Integrated with depth and significant complexity and fullness	Conceptual (refer definition)	—
Round	Integrated with depth, reasonable complexity and fullness and without any specific oral sensation dominating	Conceptual (refer definition)	—
Creamy	An impression of mouth-coating, softness and fullness	Conceptual (refer definition)	—
Supple	A soft, gentle, and frictionless impression with moderate to full body	Conceptual (refer definition)	—
Integrated	An impression that oral sensations are combined in good proportion	Conceptual (refer definition)	—
Neutral	Simple integration of oral sensations	Conceptual (refer definition)	
Disjointed	Lack of integration of oral sensation(s)	Conceptual (refer definition)	—
Insipid	Thin and lacking in complexity	Conceptual (refer definition)	—
Harsh	A rough and grating	Conceptual (refer definition)	—
Aggressive	A prolonged and significant impression of harshness across the palate	Conceptual (refer definition)	—

ple, in unpublished work from our lab, white wines were evaluated for particulate, roughness and smoothness both "in mouth" and again "after expectoration," with significant changes noted between these time-points for some samples, in agreement with findings on red wine from R. Gawel *et al.*[10]

Applications and other considerations

The white wine mouthfeel wheel should assist with more clear and precise communication between wine professionals on the oral sensations elicited by wine. It should also allow the research community to more fully describe the influence of viticultural and enological variables on wine quality.

For example, it has been used in conjunction with classic flavor-profiling techniques to examine the influence of lactic acid bacteria (LAB) strains on the texture of Chardonnay wine.[20] In that study, the influence of five different LAB strains on the texture of a Chardonnay wine as experienced in-mouth and after expectoration was examined, and compared with Chardonnay that had not been through malolactic fermentation (control).

Higher perceived acidity and acid-mediated tactile sensations such as pucker intensity explained most of the differences between control wines and those that had been inoculated with LAB. Wines produced using different LAB strains were differentiated for all three surface texture categories—smoothness, roughness and particulate. Irritation, drying and weight were also important in discriminating some strains.

In addition, the change in oral sensations during gustation also appears to be important, and some differences were found between treatments for integrated sensations, particularly volume, depth, smoothness, balance and overall impression.

In addition to traditional flavor-profiling applications, the lexicon, reference standards and evaluation protocols may find a use in consumer research, particularly with preference mapping approaches.[26] In preference mapping and related methodologies, data generated from descriptive analysis are "mapped" onto consumer preference scores and demographics to better understand sensory drivers of consumer preference and to identify potential niches in the market.

This lexicon may find application in psychophysical research by facilitating a more comprehensive and systematic examination of the differences between individuals in perception of wine stimuli. For example, G.J. Pickering and G. Robert, using a similar tool, found that an individual's "super-tasting" status (sensitivity to 6-n-propylthiouracil (PROP)) predicted their perception of a wide range of oral sensations elicited by red wines, including particulate, smoothness, mouthcoat and overall astringency.[21]

The use of finger-touch standards, first proposed by R. Gawel,[11] was universally considered by the panel as valuable in developing a common understanding of many terms, and subsequently in rating these sensations in wine. They also have the advantage compared to traditional oral standards of minimizing fatigue, carryover effects and standard preparation time. Their use and further refinement is encouraged in all studies examining non-taste oral sensations.

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Microbial origins of key wine aromas
PART I: ESTERS and ALDEHYDES

BY Russell Moss

This is Part I of a three-part series that covers the fungal and bacterial origins of wine aromas. The series will detail esters, aldehydes, volatile fatty acids, volatile phenols, sulfurous compounds and higher alcohols. The old adage "one man's trash is another man's treasure," holds true with these compounds.

A winemaker may make a Sauvignon Blanc table wine within which they would like to have dominant aromas of grapefruit, gooseberry and passionfruit and perceptible acetaldehyde would be viewed as a fault.

However, another winemaker may wish to make a wine that emulates sherry, at which point maximizing acetaldehyde production would be intrinsic to the desired wine style.

The same is also true with esters. A winemaker may wish to create a young wine that is similar to Beaujolais Nouveau or a fresh white wine that is meant for immediate sale. The formation and retention of esters during fermentation will be critical to achieve the desired wine style.

However, another vigneron may wish to make Pinotage table wine that has deep flavors of smoke, earth and a varied assortment of berries. The winemaker might view isoamyl acetate (an ester) as a fault and attempt to minimize its impact on the wine by controlling viticultural and winemaking practices which will influence this compound.

What are esters?

Esters are the class of volatile compounds that are responsible, in part, for a general "fruity" smell in wines.

They are some of the most abundant aromatic compounds within wine.[12] Esters are found in grapes in small amounts, but most of the esters in wine are formed during fermentation or during bottle development.

Esters can be classified as either volatile esters (or neutral esters) and acid esters (or non-volatile esters). Neutral esters are produced through enzymatic reactions.

Acid esters are formed in simple hydrogen-ion-catalysed esterification.[8] This simple acid-catalyzed reaction is slower than enzymatic esterification, but may be responsible for aged characters of wine. Acid-catalyzed esterification may occur faster in wines of a lower pH.[3] Therefore, esters not only contribute significantly to the sensory impact of newly fermented wine, but the aged product as well.

Volatile esters are produced in such high quantities during fermentation that the concentration surpasses the synthesis/hydrolysis equilibrium point, and they cannot be maintained. During bottle development, volatile esters decrease as they react hydrolytically and finally achieve equilibrium.[12]

Non-volatile esters contribute relatively negligible aromas and flavors in wine; however they may somewhat soften the tartness of highly acidic white wines such as from Chablis in France.[8]

Volatile esters are a major component of fermentation bouquet and rapidly dissipate after fermentation.[1] Therefore, wines destined for early release such as those sold in the northern hemisphere's autumn such as *Federweißer* (a.k.a. *neu wein*) and Beaujoais Nouveau, rely heavily on fermentation esters as part of their intrinsic character.

Ester production and the proportion of each ester is dependent upon yeast strain.[22] Therefore, the winemaker might select a specific yeast strain in order to enhance or downplay certain esters. For instance, one might use Enoferm M1 to produce a wine with a "fruit punch" type of aroma or Lalvin V1116 (K1) to impart a "floral aroma" from the esters which these yeasts are known to produce.

Types of esters

There are two groups of esters, aliphatic and phenolic. Aliphatic esters are those formed with straight chain/non-cyclic molecules (such as alcohols and fatty acids). Phenolic esters are formed from phenolic compounds, which are cyclic in nature.

However, only the aliphatic monocarboxylic esters make a significant impact in wine. The monocarboxylic acid esters can be further broken down into those formed from ethanol and saturated fatty acids. The second group are those formed from acetic acid and higher alcohols.

Monocarboxylic acids are the most significant esters for most wines. However meth- and ethanolic esters have been found to be associated in the aroma of Muscadine wines.[6] The physiological function of esters formed during fermentation is unclear.[12]

Esters can arise in two ways: from acetates, ethanol and higher alcohols or from ethanol and straight-chained fatty acids.

Esters which form from acetates, ethanol and higher alcohols include:

- Ethyl acetate, isobutyl acetate, isoamyl acetate and 2 phenethyl acetate.

Esters which form from ethanol and straight chain fatty acids include:

- Ethyl hexanoic acid, ethyl octanoic acid and ethyl decanoid acid.

The esters formed from fatty acids are not nearly as important in wine production as the acetate esters. However, they are more significant in products of distillation.[19]

Ellusive answers

The mechanism by which yeasts form esters has been theorized by many, but a consensus has not been reached. Some believe that the reaction is catalyzed by an enzyme called alcohol acetyltransferase (AAT). This reaction uses alcohol (as a substrate), co-enzyme A and ATP to form an ester.[1,9,19] Esters may also be formed through simple hydrogen ion-catalyzed reactions.

Oenococcus oeni and other lactic acid bacteria have esterases and can affect the ester concentration of a wine during malolactic fermentation. This occurs through ester synthesis or hydrolysis, which will complement or detract from wine aroma, depending on the esters produced or metabolized by the strain.[2]

Esters are usually associated with "general fruit" rather than attributing a specific aroma; however, they are not always pleasant (such as ethyl acetate).[12,19] Ethyl acetate, which has a detection threshold of 12 to 14 mg/L, is also present in acetic acid and contributes to the vinegar (or nail polish) aroma at 120 to 160 mg/L. The perception of volatile acidity as a fault is a function of the ethyl acetate:acetic acid ratio.[8,12]

Significance less understood

Esters are generally thought to be more important to the aroma of white wines; their significance in red wine aroma is less understood.

However, esters are critical in the production of many wines, especially those made from Pinotage. If uncontrolled, this varietal wine is capable of developing a pungent, banana aroma from isoamyl acetate, which is produced during fermentation and at excessive concentrations may be viewed as a fault.[18]

Esters can also be a major contributor to varietal aroma. This is especially true in Pinot Noir from Burgundy, which contains four particular esters that contribute to its characteristically fruity aroma.[10]

Native yeasts such as *Hansenula anomala* and *Kloeckera apiculate* produce an abundance of ethyl acetate. Therefore, yeast strain can affect the formation of certain esters. C. Lema found that the concentration of total esters was more dependent on the size of the initial yeast culture, rather than the yeast strain itself.[7] However, the concentration of the esters produced was different from strain to strain.

Saccharomyces yeast generally produce roughly the same concentrations of esters, but their distribution differs. Non-*Saccharomyces* yeast can produce many more esters than *Saccharomyces,* but may not always be pleasant. Nonetheless, this may be a reason why natural fermentations produce wines of greater complexity.[1]

Volatile esters are an important component of the fermentation bouquet, and they rapidly dissipate after fermentation.[1] Must conditions such as high solids and high fermentation temperatures (above 15° C), can decrease the amount of potential esters formed during fermentation.[1,8] Further, if oxygen is dissolved within the must, this may minimize ester production.[21] The use of sulfur dioxide and other antioxidants such as glutathione, caffeic acid and gallic acid can aid in the retention of esters in the bottle.[20]

Aldehydes

Acetaldehyde constitutes around 90% of all the aldehydes found in wine. It is a normal yeast fermentation by-product and is an intermediary in the process of diacetyl forming from pyruvic acid.[12]

Acetaldehyde is the penultimate compound produced during the conversion of sugar to ethanol. Sugar is metabolized through glycolysis, which allows for the formation of ATP and NADH, providing cellular energy. The end product of glycolysis is two pyruvate molecules. Pyruvate is then enzymatically decarboxylated to form acetaldehyde. Acetaldehyde is then enzymatically converted to ethanol.

However, not all the acetaldehyde produced by the yeast cell is converted to ethanol, as it is used to maintain a redox balance within the cell. Some acetaldehyde remains in the cell, some is excreted, and the remainder is converted into alcohol. Notably, ethanol is able to oxidize back into an aldehyde.[16]

Acetaldehyde can also increase in wine through enzymatic oxidation of ethanol by film yeast. These yeasts utilize ethanol as their primary carbon source for growth. Film yeast are regularly exploited in the production of sherry, but must be controlled when creating table wine.

Yeast differ widely in their ability to produce acetaldehyde. In general, low acetaldehyde-producing yeast generate less acetic acid and acetoin than their higher-producing cousins.[14] Therefore, these yeast can be selected to create a more "fresh" wine style.

Cellar temperature during bulk wine storage is critical for control of film yeast. Temperatures of 8° C to 12° C are ideal to restrain oxidative yeast film formation.[19]

Aldehydes commonly convey a nutty or bruised apple aroma.[16] This compound is intrinsic to oxidative wine styles, such as sherry and *Vin jaune* (yellow wine). However, where these characteristics are desired in the aforementioned styles, they are viewed as a fault in typical table wines. Where aldehydes are intrinsic to the Savagnin-dominant *Vin jaune* wines of Jura, aldehydes in the *Vin de paille* (also Savagnin-dominant) wines from this region, would be viewed as a fault.

Color link

Besides affecting wine aroma, aldehydes may be intricately linked to color development of red wines. Aldehydes interact with phenolic compounds during bottle development, which promotes the formation of tannin-anthocyanin polymerization. However, the role of acetaldehyde in wine color stability may be of little to no significance.[15,16,17]

Free acetaldehyde in young wine is usually less than 75 mg/L. Although, if oxidative reactions induce higher acetaldehyde concentrations then SO_2 is used to neutralize the aromatic impact of acetaldehyde and form the less aromatic product, acetaldehyde-α-hydroxysulfonate.[19] It requires 1.45 mg of SO_2 per milligram of acetaldehyde for the latter to be completely "bound."[5]

Unfortunately, SO_2 is not always a positive tool in decreasing the sensory impact of acetaldehyde. Increasing amounts of pre-fermentative SO_2 correlates with higher acetaldehyde production, since SO_2 inhibits aldehyde dehydrogenase, which converts acetaldehyde to ethanol.[4,13] Further, incorrect timing of the SO_2 addition leads to degradation of acetaldehyde-α-hydroxysulfonate by lactic acid bacteria, thereby releasing SO_2 and halting, or prolonging malolactic fermentation.[11]

Conclusion

Wine is commonly referred to as a "complex matrix." By breaking wine down into its fundamental components, we can begin to understand how to better manage our vineyards and wineries to attain the wine styles that our markets desire.

Esters and aldehydes could be considered a fault or aromas that are intrinsically valuable to a wine style, depending upon what we are trying to achieve.

It is crucial to understand how these compounds arise and how vintners can manage them effectively and efficiently. PWV

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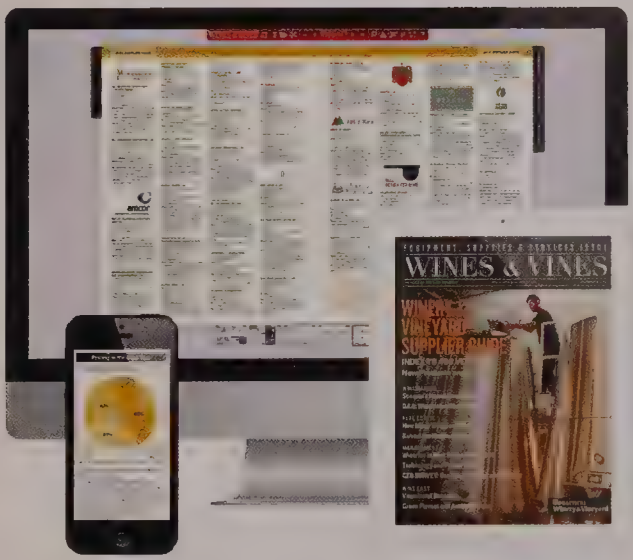

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STICKINESS New concept in grape and wine tannin analysis

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There is an incredible range of sensory descriptors that refer to red wine tannin. Words such as silky, velvety, dusty, green or hard have all been used by winemakers, wine writers and consumers from around the world when referring to tannins in wines. What is the underlying chemistry that leads to these descriptors?

Developing a standardized vocabulary of mouthfeel descriptors[1] and the chemistry responsible for these descriptors[2] is essential if we are to effectively manage red wine mouthfeel in the vineyard and winery.

Our goal as tannin researchers is to understand the chemistry of astringency so that viticulturists and winemakers can manage mouthfeel and astringency more effectively.

Red wine tannins are derived primarily from the skins and seeds of grapes and are extracted during fermentation and maceration.[3] The concentration of this extracted tannin plays a significant role with regard to astringency, but it does not tell the entire story—anecdotes abound regarding wines that have similar tannin concentration but have textural mouthfeel characteristics that are inexplicably different.

For example, the transformation of red wine mouthfeel during micro-oxygenation is an indication that wine matrix components (Figure 1), while important in tannin perception, do not fully explain mouthfeel descriptors. In order to better understand tannins within wine, we need to develop a methodology to determine not only the tannin concentration but also how **active** that tannin is.

Astringency and mouthfeel management

Astringency in red wine is considered to be a result of the precipitation of salivary proteins by tannins and/or the binding of tannins to our oral mucosa.[2] Tannin structure and subsequently the astringency of wine is modified throughout the various winemaking processes and proceeds through development in the bottle of the finished product.

Astringency perception in wine may be modified in several ways that we can broadly refer to as mouthfeel management (Figure 2). The "wine matrix" plays a role with acidity, alcohol concentration, residual sugar, mannoprotein and polysaccharides all contributing in various ways to the mouthfeel of a wine.

Acidity, for example, in wine increases both bitterness and astringency, while an increase in alcohol concentration reduces perceived astringency while increasing bitterness and contributing to the "body" of a wine.[2,4,5] Residual sugar contributes to the sweetness of wine, which attenuates astringency.

Yeast-derived mannoproteins and grape-derived polysaccharides interact with tannins in wine and can inhibit their astringent qualities. In a perfect world, knowing the tannin composition and concentration would tell us all we need to know about the perceived astringency it would produce, but wines are never that simple.

Research has shown that astringency correlates with tannin concentration, In general, the higher the tannin concentration, the more astringent the wine becomes.[6] However, tannin compositional effects such as skin/seed tannin proportion, polymer size distribution, color incorporation and degree of oxidation are all considered to be of critical importance to understanding the sub-qualities of astringency in wines.[2]

Skin tannins are less bitter and astringent than seed tannins and greater proportions of skin tannins have also been found to correlate with higher perceptions of quality and price point.[7,8] The size of tannin polymers also has an effect with larger (higher molecular mass) tannins correlating with an increase in perceived astringency.[9]

> Tannin compositional effects such as skin/seed tannin proportion, polymer size distribution, color incorporation and degree of oxidation are all considered to be of critical importance to understanding the sub-qualities of astringency in wines.

Recently, a great deal of attention has been given to the incorporation of anthocyanins (the phenolic responsible for color in red wine) into the tannin polymer. Referred to as pigmented polymer, these tannin-anthocyanin products are thought to be less astringent.[8] Tannin oxidation during *élevage* and develop-

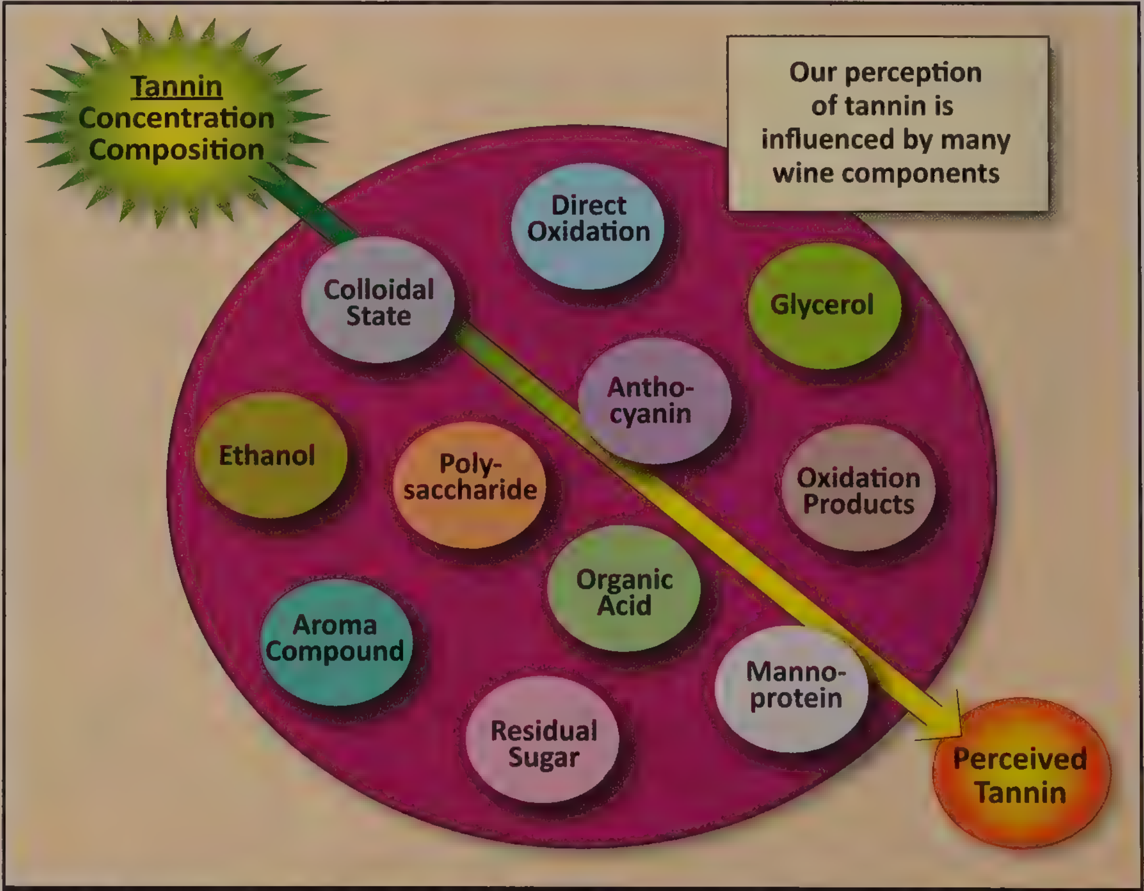

Figure 1. Generalized view of the role that tannin concentration and composition, in conjunction with wine matrix elements, play in mouthfeel description.

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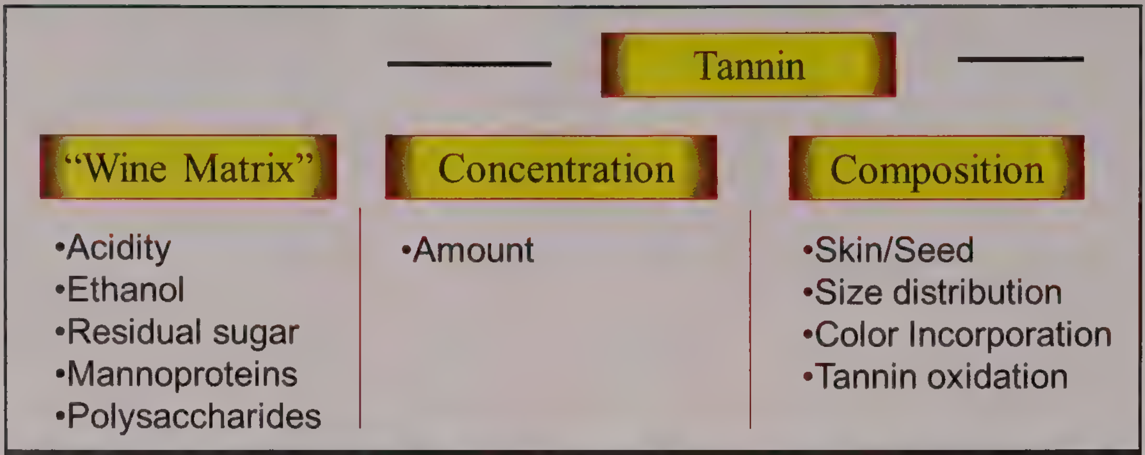

Figure 2. The management of red wine mouthfeel generally encompasses the management of the attributes shown above.

ment in bottle is generally considered to influence perception by modifying tannin interaction through structure and shape modification.[10]

Protein-tannin interaction, stickiness concept

In order to better understand the role of tannin structure in red wine astringency, it is helpful to understand how tannin interacts with other molecules, including proteins.[11,12,13,14,15,16]

From previous studies on the interaction of tannins with model proteins,[17,18,19] a three-stage process can be proposed where the initial stage of interaction is consistent with a hydrophobically-driven interaction (a chemical force that drives the molecules together).[20] Subsequent stages including aggregation of tannin-protein complexes (the second stage), and precipitation of aggregates (the third stage). Based upon current evidence, this process includes both hydrophobic interactions and hydrogen bonding, with the bottom line effect being that tannin likes to "stick" to protein.

The precipitation of salivary proteins by tannins has been considered to create a loss of lubricity in the mouth, which is responsible for the sensation of astringency. Studies have shown that tannins isolated from skins interact differently with proteins than tannins extracted from seeds.[20]

Tannin structure variation has been shown to influence the extent of hydrophobic interaction and it can be quantitatively measured. It is hypothesized that the extent of hydrophobic reaction between tannin and salivary protein is related to the ability of hydrophobic surfaces to interact (Figure 3).

To conceptualize tannin stickiness, the following is proposed. A young tannin that would be typical of a pre-*veraison* grape would have a more rod-like structure that would have more surface available for interaction with salivary protein.

However, more modified tannins in matured wines would contain more complex intramolecular bonds and structure thus developing a more globular shape due to structure modification, resulting in less available surface for interaction. The goal of our research is to develop analytics that can more routinely measure the ability of tannin to interact with a hydrophobic surface (hereafter referred to as stickiness).

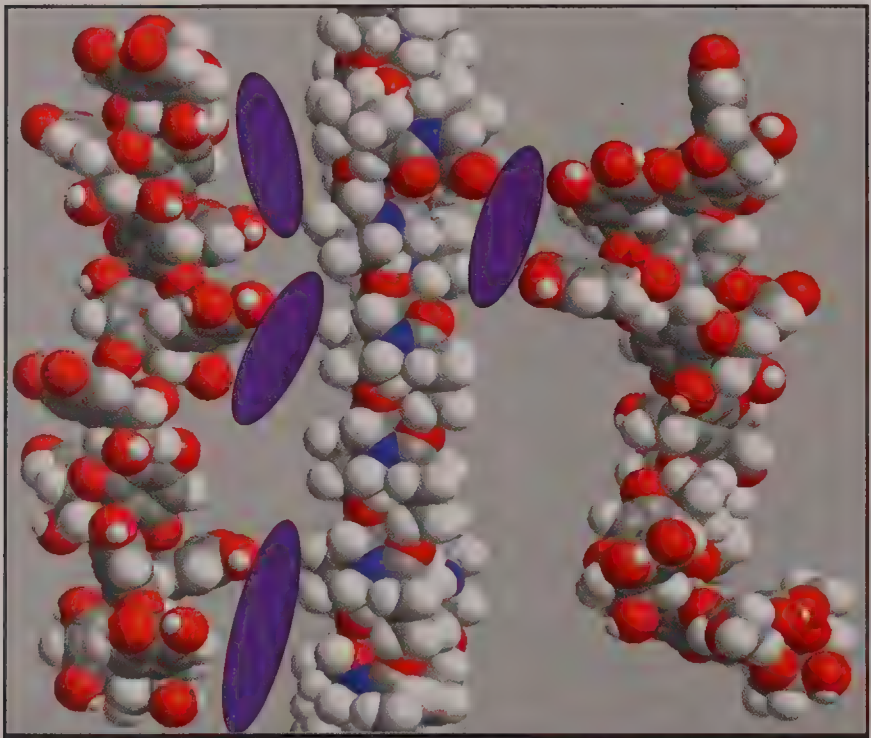

Figure 3. Model conceptualizing tannin hydrophobic interaction with salivary protein. In this model, a grape-derived tannin (left), a proline repeat that is particularly abundant in salivary proteins (middle) and an aged tannin (right). Purple ovals indicate regions available for surface interaction.

Recent developments in determining the shape of tannin structures provides supporting evidence for this shape transformation.[10] As stated above, tannin shape modification with red wine age is postulated to ultimately lead to a reduction in the surface available for interaction between tannin and protein, resulting in the tannin being less sticky (Figure 3). This transformation is consistent with sensory evaluation of older wines and the "softening" effect that occurs. With this interaction in mind, a high performance liquid chromatography (HPLC) method was developed to measure tannin stickiness.

In an effort to measure stickiness, and based upon earlier findings,[20] an HPLC method that measures the extent to which tannin interacts with an HPLC column, was developed.[21] The HPLC method consists of a polystyrene divinylbenzene column that would only allow for hydrophobic interactions—the same chemical interaction during the initial stage of tannin-protein interaction, and was modified from a previously published method.[22] After initial success, this HPLC method was further modified and tested.[23]

Tannin stickiness is concentration-independent and therefore adds to the analytical information available.

To acquire stickiness information for the tannin in question, each sample is analyzed at four different column temperatures, and from this temperature response, the stickiness of the tannin towards the HPLC column can be calculated.[24] In addition to stickiness, this HPLC method can also provide concentration information.[23]

Tannin stickiness is unique and different than concentration

Operating under the hypothesis that stickiness is a property of the tannin rather than a function of its concentration in the system; it was predicted that stickiness would not be affected by concentration. To investigate this, wine or tannin solutions were serially diluted across a large concentration range (from 7408-225 mg/L) and the results showed

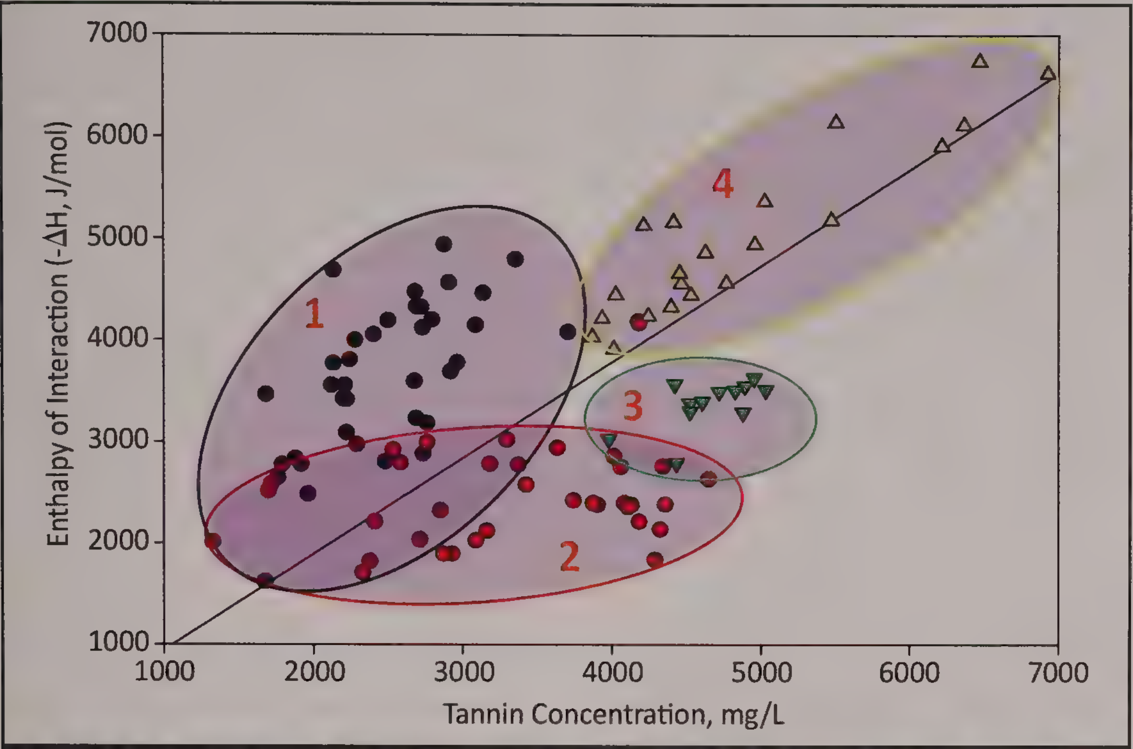

Figure 4. Analysis of wines with groups separated by numbers; Paso Robles Bordeaux wines (1), research-scale California Cabernet Sauvignon wines (2), 2009 Bordeaux wines (3), 2012 North Coast estate-grown barrel samples (4).

that regardless of tannin concentration, the stickiness did not vary (-4905 ± 153 J/mol). This finding is critical because it shows that tannin stickiness is an intensive property—an attribute that is independent of concentration.

The above finding was strengthened by the standard addition of exogenous tannins to a wine. In this experiment, the stickiness of the resultant tannin was found to be dependent on the fractional contribution of the stickiness of individual tannins as opposed to their concentration. This finding indicates that this new analytical method not only measures the concentration of tannin within the sample, but how sticky that tannin is. With this finding, we decided to examine this new stickiness parameter with initial experiments designed to show the potential significance of tannin stickiness.

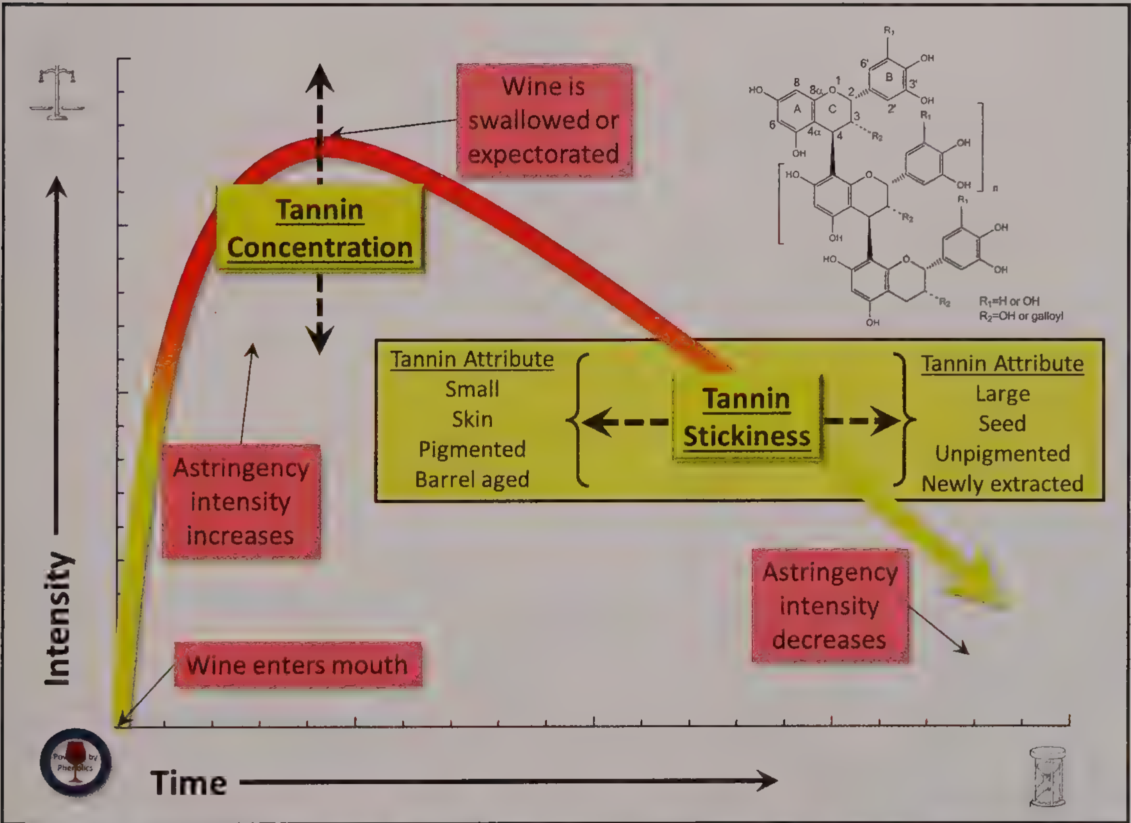

Figure 5. Time-intensity graph indicating astringent response to tannins and with proposed effect of tannin concentration and stickiness on sensory response.

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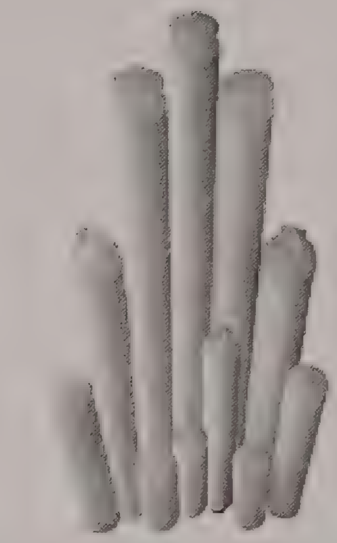

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In order to explore the potential applications of this method in a winemaking application, a gelatin fining trial was conducted. The results were consistent with prior observations that the gelatin preferentially removed higher molecular mass tannins, or stickier tannins. In other words, not only did the concentration of tannin decline, but also the stickiness of the remaining tannin. This finding is in contrast to a dilution experiment where concentration is effected while stickiness is not.

A set of wines was analyzed in order to gain insight into the variation of stickiness in a set of commercial Bordeaux varietal wines. California wines were sourced directly from the winery and Bordeaux wines were purchased from a wine shop. This data set varied by age and region, and the analytical results are shown in Figure 4.

The set of wines showed that tannin concentration and stickiness varied considerably and that there was a broad range of stickiness values possible at any given concentration. There was also a poor correlation (r = 0.24) when stickiness values were plotted against concentration values, which reinforces the finding that tannin concentration and tannin stickiness are independent and unique variables.

Sensory relevance of tannin stickiness

Tasting wines with similar tannin concentrations and different stickiness values – and conversely tasting wines with different tannin concentrations but similar stickiness values has been the focal point of preliminary uncontrolled sensory sessions, with promising results. The researchers have worked in collaboration with winemaking teams in California and found good correlations between analytical values and sensory descriptors, albeit with a limited data set.

Conceptualizing the perceptual difference between tannin concentration and stickiness under wine tasting conditions is hypothesized as follows (Figure 5). The concentration of tannin in wine is related to the astringency maximum while stickiness is related more to its duration. This variation in astringency time-intensity is hypothesized to be related to variations in astringency sub-qualities.

Preliminary sensory experiments have shown that tannin stickiness correlates with distinct tactile qualities in wine; however, further more controlled sensory studies are required. Linking sensory data to these analytical results is the next phase of this research.

Funding from the American Vineyard Foundation (AVF) and the California State University Agricultural Research Institute (CSU-ARI) has been secured and will involve Dr. Hildegarde Heymann at the University of California, Davis. We are currently building a large data set of wines in order to target wines with specific stickiness attributes that can then undergo sensory studies.

Wineries that are interested in participating in this study and would like to submit samples for analysis, are encouraged to contact Dr. James Kennedy in the Department of Viticulture & Enology at Fresno State (jakennedy@csufresno.edu).

Summary

This method shows promise with regards to processing decisions that influence tannin composition including grape maturation, pressing, racking, micro-oxygenation, *élevage*, fining and filtering. The fining trial and exogenous tannin addition experiments in this study showcased the applicability of this method to practical winemaking scenarios, and current projects including extended maceration and additional fining trials.

The novel information that this approach captures has the potential to demystify some of the more frustrating issues of tan-

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nin, astringency and overall mouthfeel quality. This new approach may help winemakers to better identify the influence of various winemaking practices on tannin stickiness, and identify wine mouthfeel attributes objectively. PWV

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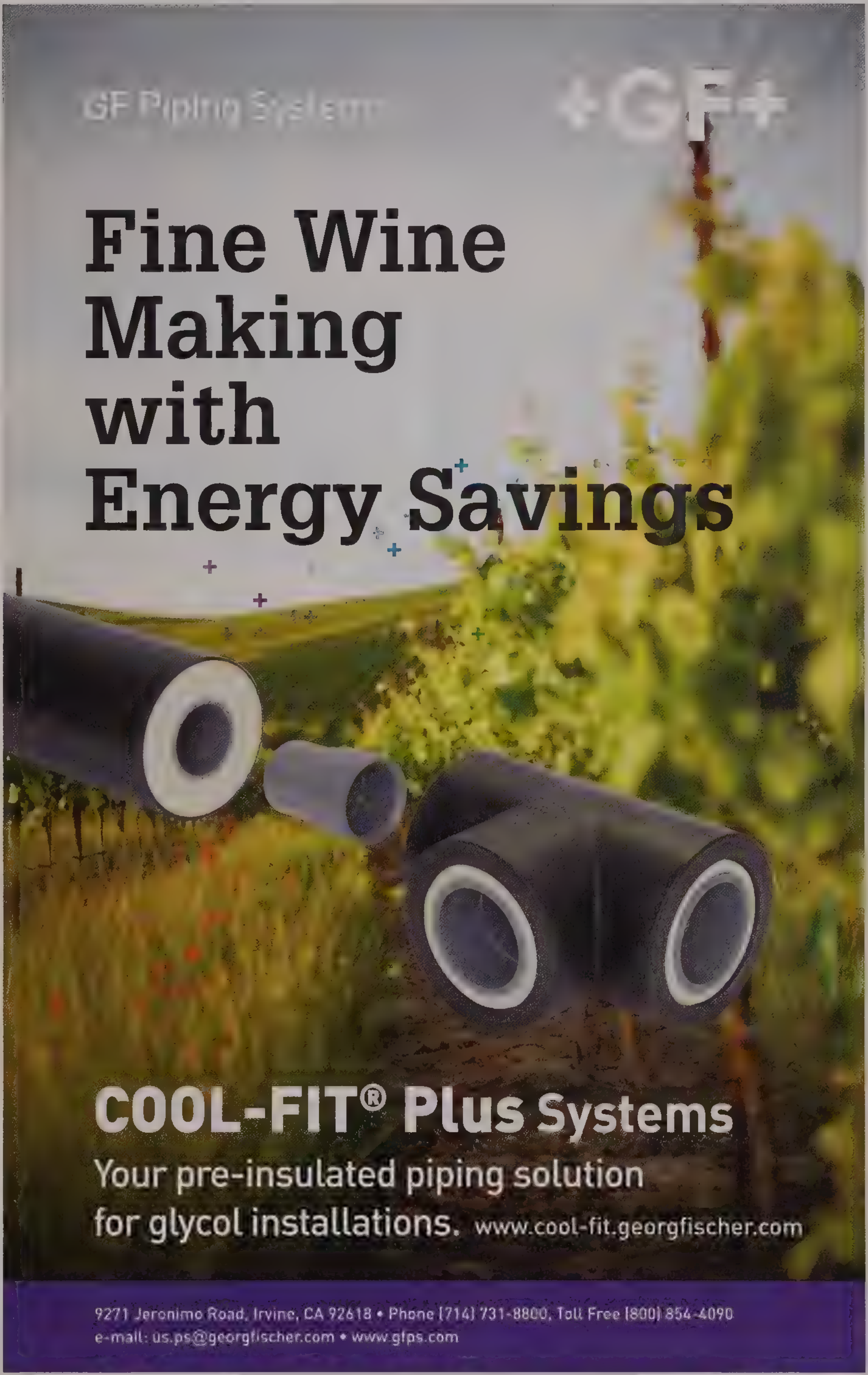

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Oxygen transmission through different closures into bottled wine

BY Paulo Lopes,* Maria Silva, Cédric Saucier, Pierre-Louis Teissedre, Yves Glories, UMR1219 Oenologie, Faculté d'Oenologie - ISVV, Villenave d'Ornon France.
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Achieving the optimum wine style is extremely dependent on the amount of oxygen a wine receives during the winemaking process.[1] In a complex matrix such as wine, oxygen can be involved in many reactions that affect compounds of sensory importance. Oxygen will have a great impact on consumer acceptance and preference[2,3]

In a finished wine, the total package oxygen (TPO) consists of the oxygen concentration at the time of bottling plus any oxygen introduced after bottling. Oxygen at bottling represents the sum of dissolved oxygen in the wine plus any remaining oxygen present in the bottle headspace (dependent on variables of volume, pressure and gas composition). Oxygen ingress after bottling depends on the oxygen transmission characteristics of the closure. The latter depends on the inherent oxygen permeability of each wine closure.

This article will summarize 10 years of research at the Bordeaux Faculty of Oenology to understand the oxygen transmission properties of different wine closures and assess their impact on the chemical and sensory qualities of wine during post-bottling.

Method to determine closure oxygen transmission rate

Ten years ago, there was little knowledge and understanding about the oxygen transmission of wine closures. There were no techniques and methods to measure the oxygen transmission rate (OTR) of closures under realistic bottling conditions.

In 2005, the Bordeaux Faculty of Oenology developed a non-destructive method to determine the amount of oxygen entering the wine bottle according to the type of closure. This colorimetric method is based on the color change from the oxidation-reduction reactions of the indigo carmine. It allows a single bottle to be continually analysed over time, without compromising the closure seal.[4]

The method measures oxygen ingress through a closure by direct colorimetric scan of colorless wine bottles (375 mL) containing indigo carmine solutions that gradually change color from yellow to indigo as oxygen reacts with the reduced indigo carmine. Details concerning this methodology are provided in Lopes *et al.*[4,5,6]

The great advantage of the colorimetric method is that it uses authentic closures and wine bottles stored under realistic wine conditions. One of the driving forces for oxygen transfer is the relative concentration of oxygen between the headspace and outside air. As oxygen from the headspace dissolves into wine, the balance of concentration changes and increases the rate of oxygen transmission.[7] The reaction of oxygen with the indigo carmine allows the colorimetric method to duplicate the change in concentration seen in actual wine storage.

Initially, the method was used to monitor oxygen entering into wine from the external environment by permeation through the closures and/or between the closure-glass interface.[4,5] Subsequent work demonstrated the method also detects oxygen released by diffusion from air contained in the compressed closure itself.

Several commercially available wine closures were tested: two natural cork stoppers (45 x 24 mm), the best grade ("flor"), and the intermediate grade

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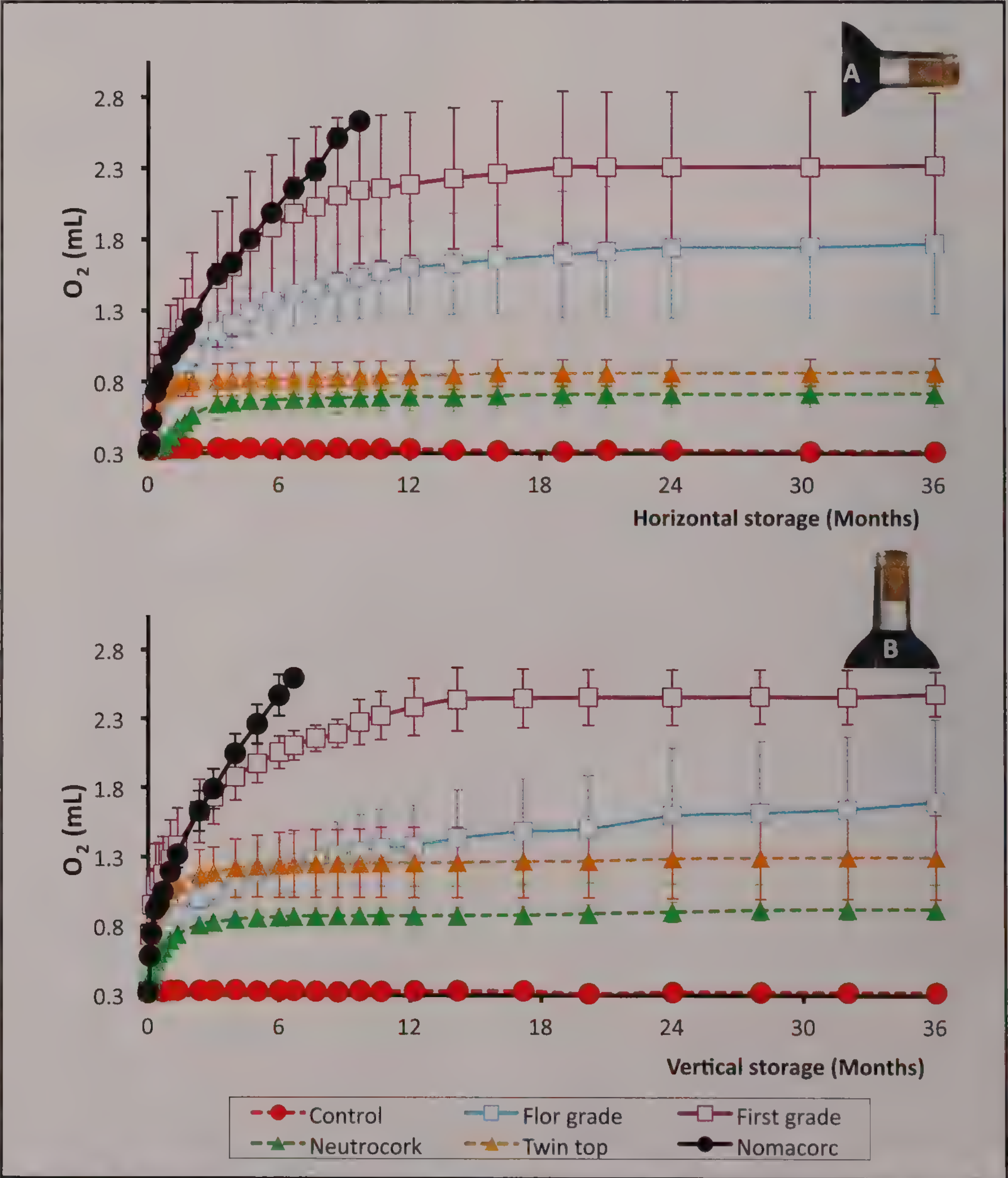

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Figure I. Kinetics of oxygen ingress through different closures into wine bottles stored in horizontal position (A) and vertical position (B) over 36 months. Error bars represent the standard deviation of four replicates.

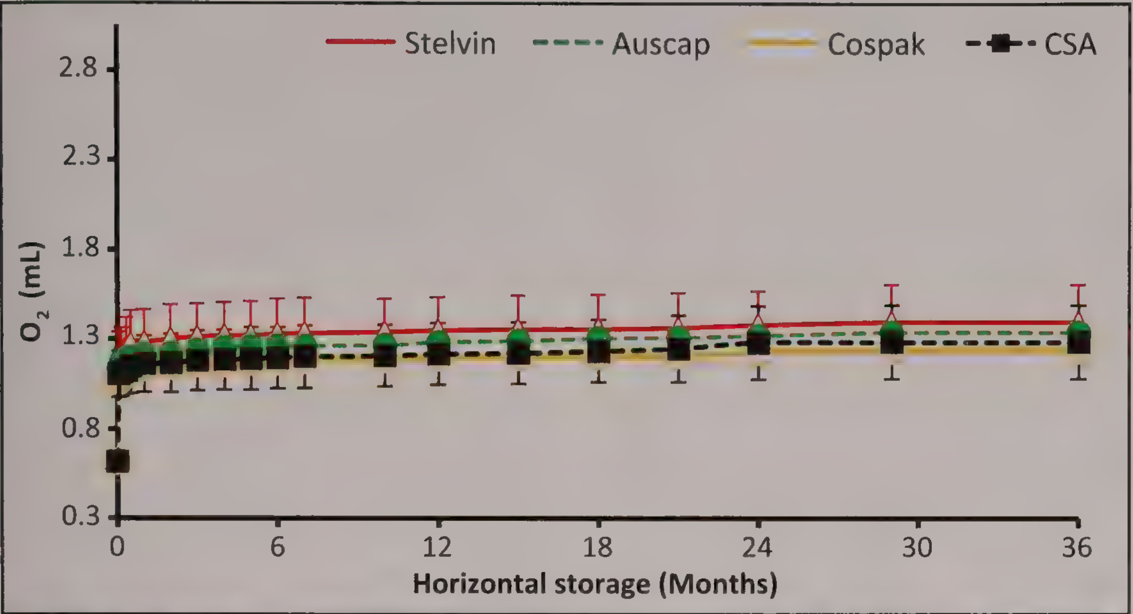


Figure 2. Kinetics of oxygen ingress through screw cap closures into wine bottles stored in horizontal position during 36 months. Error bars represent the standard deviation of four replicates.

(first); two "technical" cork stoppers (Twin Top and Neutrocork); one synthetic closure, Nomacorc classic closure (43 x 22 mm) and four screw cap (Saran-tin liners) closures (Stelvin, Auscap, Cospak, and CSA). An airtight bottle containing a reduced indigo carmine solution, sealed by flame, was used as a control. All bottles were sealed and then stored horizontally and vertically under constant temperature of 20±1 °C and constant relative humidity of 65±1%.[5]

Oxygen transmission kinetics through closures and their OTR

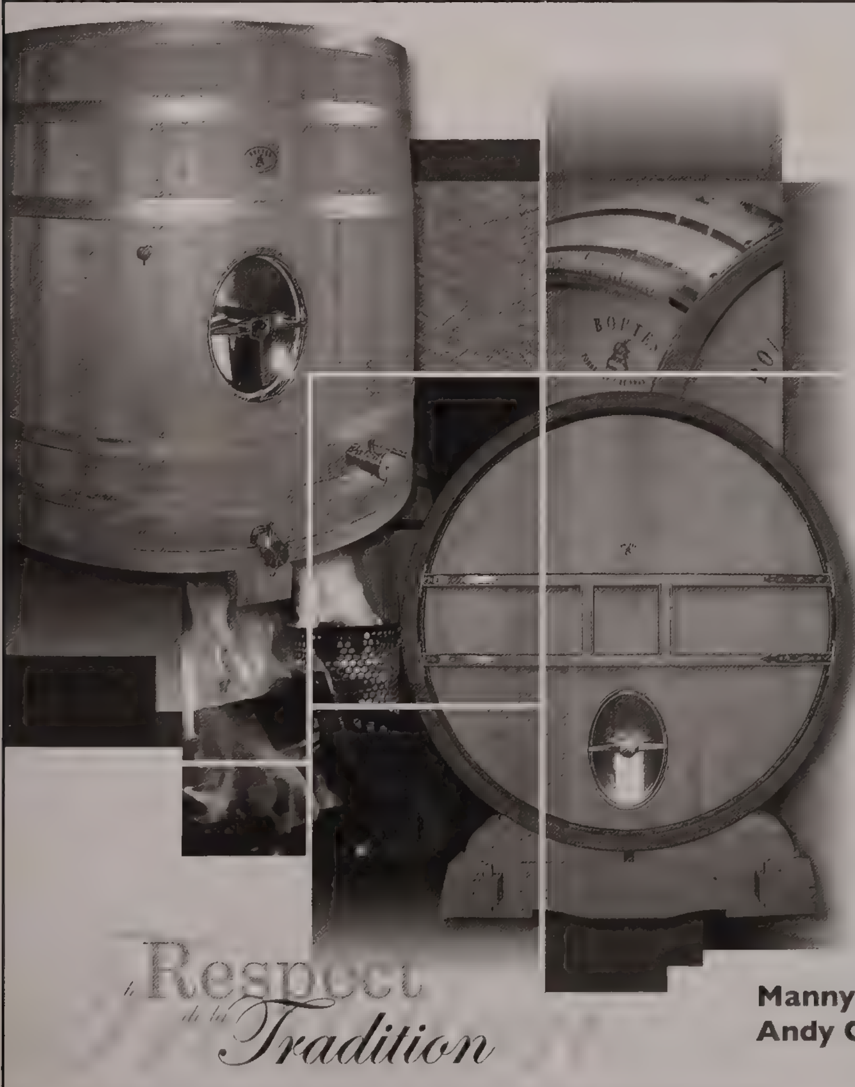
The kinetics of oxygen ingress through different closures into bottled wine stored horizontally and vertically for 36 months is shown in Figures 1 and 2.

Results showed that only the control (bottle sealed by flame) was completely air-tight, other closures allowed wine oxygenation. It was observed that the oxygen ingress kinetics have different phases, which vary according to type of closures.[4,5]

For cylindrical closures such as corks and synthetic, there is an initial phase of one month where the oxygen pickup is much more important than in the following months of storage. This phase is likely a result of oxygen introduced at bottling due to the "piston effect" during the descending movement of closures into the bottleneck. In addition oxygen is expelled from the closure into the bottle after compression and insertion.

In the second phase, cylindrical closures display oxygen ingress at a more consistent rate. Their transmission is a result of either permeation through the closure, or diffusion of gases retained in the compressed closure. Permeation is seen as a steady transmission where diffusion is limited by the gas and pressure found in the compressed closure. The total oxygen ingress in this phase is extremely dependent on the inherent oxygen transmission characteristics of each closure type.

With the screw cap closures, the apparent entry of oxygen into wine



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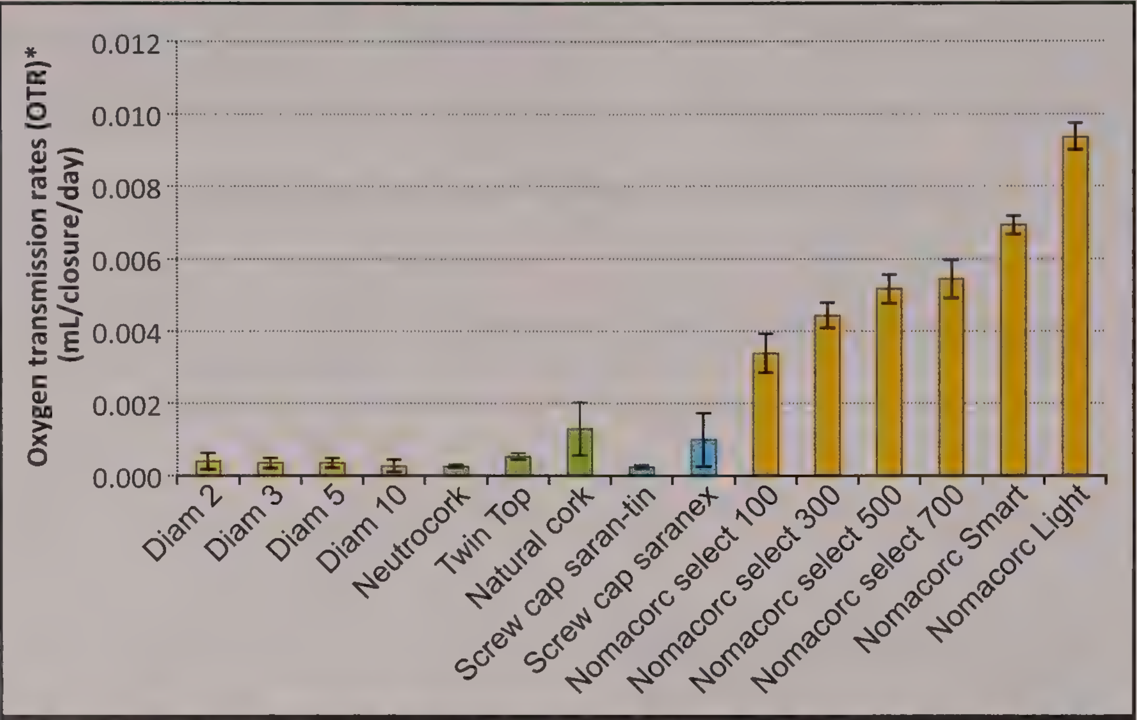


Figure 3: Oxygen transmission rates (mL/closure/day) of different closures. OTRs were obtained from colorimetric measurements done during 24 months of horizontal storage at room temperature. The values obtained in the non-steady state (first month) were not included in the calculations. Error bars represent the standard deviation of 10 replicates for technical corks, synthetic and screwcaps, and 100 replicates for natural corks.

bottles was substantially greater during bottling than in the following 36 months of storage. This appeared to be due to the insertion of oxygen contained under the screw cap in the bottle headspace at the time of sealing.

After the first month, screw caps and "technical" cork stoppers (Twin Top and Neutrocork) exhibited the lowest oxygen transfer rates (less than 1.0 µL of oxygen/closure/day) (Figure 1 and 2). In contrast, a synthetic closure such as Nomacorc classic, exhibited the highest oxygen transmission rate, reaching the quantifiable limit of our method (2.5 mL of oxygen) within 7 to 10 months depending on bottle orientation.

The oxygen kinetics for natural corks differed from other closures (Figure 1). Generally, oxygen ingress through natural corks decreased over time, reaching a steady state between 18 and 24 months of storage. On average, the best grade of natural cork stoppers ("flor") exhibited lower OTR, 0.6 to 1.4 µL of oxygen/closure/day, than the cork with more lenticels (first grade), 0.7 to 6.1 µL of oxygen/closure/day.

In addition, it was observed that storage orientation did not significantly impact the oxygen transmission properties for cylindrical closures (Figure 1B). Contact with liquid is an important factor in oxygen transmission through natural corks. But even in upright storage, the relative humidity inside the bottle is maintained at 100%. This is sufficient to keep the cork moisturized.

Mechanisms of oxygen ingress into bottles

Using the above mentioned colorimetric method P. Lopes and co-workers were also able to determine the main routes of oxygen ingress through synthetic and cork closures.[6] For synthetic closures, the data indicated that after the first month, when oxygen is expelled from the compressed closure, oxygen ingress is a result of gas permeation through the closure's central foam core. This permeation occurs at a constant rate over time.

In contrast, the main source of oxygenation in bottles sealed with technical and natural corks is from oxygen compressed within the closure's internal structure. This is diffused into a bottle essentially during the first several months of storage. Atmospheric oxygen entering throughout the cork-glass interface or throughout the cork is negligible.

Recent studies suggest that oxygen transport within natural corks occurs by diffusion through a gas phase in large spaces such as lenticels, plasmodesmatas (microscopic channels that make the communication between cells) or inside of empty cells following the Fick's or Knudsen mechanisms.[8,9,10]

These results were also confirmed by P. Lopes and co-workers, who showed that exogenous gases and volatile compounds such as TCA and volatile phenols are able to permeate through synthetic and screw cap saranex (more permeable liner) closures into bottled wines.[11,12] In contrast, these compounds were essentially retained in the outer cork stoppers, preventing the migration of this compound into bottled wines, showing that corks are effective barriers to the transmission of exogenous gases and volatile compounds.[13]

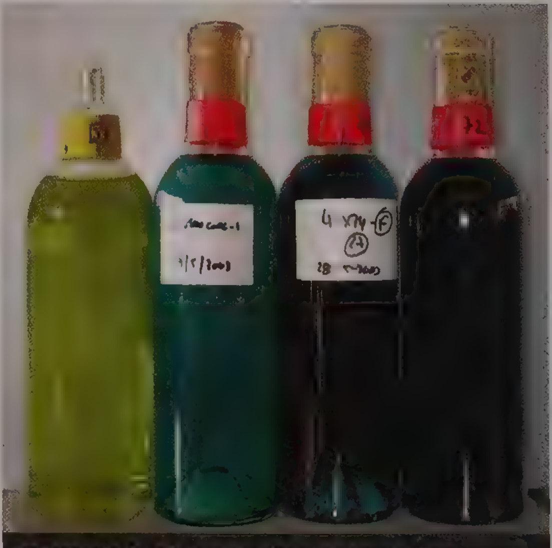
Recent results on closure OTR

In the past several years numerous changes have occurred in the closure industry with some products discontinued, new closures introduced into the market and developments in the manufacturing process designed to improve the performance of existing products.

Given this scenario and the increasing recognition of the importance of closures by the wine industry, it became pertinent to determine the Oxygen Transmission Rate of closures recently introduced to the wine market, and/or update the OTR of existing closures. The colorimetric method developed by P. Lopes and co-workers has been used to monitor and determine the OTR of current commercially available wine closures under realistic conditions.[4,5]

Overall results show some material changes in OTR performance, but the general trends by closure type are consistent with results in previous studies (Figure 3).

Today, the largest synthetic manufacturer offers a range of closure permeability, varying from 3.4 µL of oxygen/closure/day for the Nomacorc Select 100 to 10.0 µL for the Nomacorc Light.



Bottle #1 [left] (control) contains indigo carmine solution after 36 months of horizontal storage. Bottle #2 contains indigo carmine solution sealed with "technical" Neutrocork® cork stopper after 36 months of horizontal storage. Bottle #3 contains indigo carmine solution sealed with natural cork stopper after 36 months of horizontal storage. Bottle #4 [right] contains indigo carmine solution sealed with Nomacorc Classic® synthetic closure after 10 months of horizontal storage.

Although, some of these performances represent an improvement compared to previous results, the synthetic closure OTRs are still much more significant than exhibited by corks and screw-caps. Screw caps also have introduced closures with different oxygen transmission rates based on permeable internal liners. Saran-tin displays a very low OTR (less than 0.5 µL of oxygen/closure/day), saranex is slightly more permeable at 1.0 µL.

The observed OTR for natural cork stoppers was quite similar to results in previous studies. At a level of 1.3 µL per day, the OTR was lower than seen with synthetics and higher than seen with screw caps. With cork's primary oxygen pathway observed by diffusion, ongoing OTR is reduced over time.

Technical corks (Neutrocork and Twin Top) and cork-based closures such as Diam display a very similar performance, exhibiting a consistent low OTR around 0.5 µL of oxygen per closure per day.

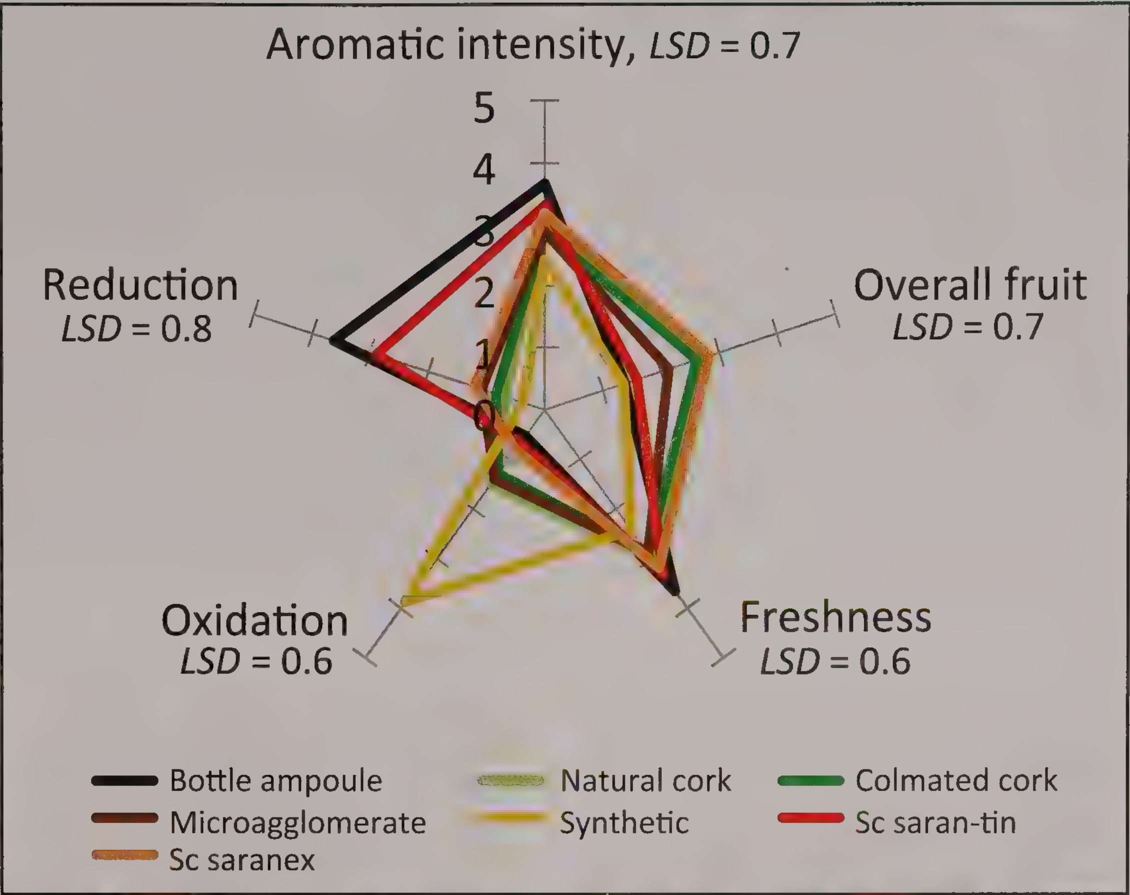


Figure 4: The effect of closure treatment on selected sensory attributes for a Sauvignon Blanc wine after 24 months of storage. The values are the means of five replicates. Least significant differences *(LSD)* at the 5% level are indicated.

Impact of closure OTR on chemical and sensory composition of bottled wines

Several closure trials have been conducted since 1999 in order to understand how closure selection and their comparative OTR will impact wine flavor development during post-bottling.[14-21]

The different OTR properties of each tested closure explains the large divergence in composition and sensory prop-

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erties of wines.[14,15,16,17,18,19,20] High oxygen transmission rates, as exhibited by synthetic closures, result in wines with a high level of browning and high-oxidized characters (honey, bruised apple, cooked fruits and aldehydic port-sherry like aromas).[14,15,16,17,18]

Very low OTR, as is generally shown by screw-cap closures with saran-tin liners, promote the development of reductive characters (sulfide-like aroma characters, rubbery, struck flint, cabbage, rotten eggs and sewage-like aromas).[14,15,16,17,18, 22,23] Low OTR values as exhibited by cork stoppers led to balanced oxidative-reductive wine development with the retention of fresh fruity characters combined with an increasing flavor complexity over time.[14,15,16,17,18]

These broadly defined trends have been evident in numerous closure trials conducted worldwide. For example, Figure 4 has the 24-month sensory results for an unoaked Sauvignon Blanc sealed with eight different closures.[18] In this case, Sauvignon Blanc style development is consistent with variations in oxygen content at bottling, and variances in closure OTR.

Wines displaying the highest oxidized characters associated with high color development (high OD 420 nm, C*, b*) and high concentration of oxidative compounds such as sotolon (spicy nutty aromas) are consistent with those either subjected to high oxygenation at bottling and/or those sealed under closures with a high OTR.

A closure with a low OTR such as natural cork, colmated and screw cap with saranex liner generated fresh tropical fruit wines with a relatively balanced concentration of varietal thiols, antioxidant compounds and color development.

Some wines with strong reductive, "rotten egg" and "putrefaction" characters due to their high levels of H_2S, were detected in those bottles sealed with very low OTR closures such as the bottle ampoule and screw cap saran-tin.

Conclusion

The studies referenced in this article show that while wine matrix composition and storage conditions such as temperature strongly influence wine maturation in the bottle, the ultimate flavor development over time can be mediated by the oxygen concentration at bottling and OTR properties of the closure.

Closures that promote high and continuous atmospheric air exposure strongly accelerate wine development towards oxidation, damaging irreversibly wine sensory properties. Strict oxygen management before and at bottling, combined with the use of a low OTR closure can make an important contribution to preserving the varietal fruity and floral characters while minimizing deleterious reductive compounds.

Different wine sensory characteristics caused by closure selection can strongly impact consumer preference and enjoyment of the wine and may play an important role in purchase intent.[2,25] Appropriate oxygen management at bottling and closure selection present an excellent opportunity to optimize wine quality that will be presented to consumers. PWV

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Grape-specific trellises in Sierra Foothills vineyard

Cedarville Vineyard in the Sierra Foothills of El Dorado County, northeast of Sacramento, Calif, was introduced to me by Don Neel, ***PWV*** editor. The vineyard is owned by University of California Davis enology graduates Jonathan Lachs and Susan Marks, and is making its mark in a region where the reputation is for Zinfandel wines.

Lachs and Marks met at Davis and graduated in 1983. They worked in the wine industry in Napa Valley and Central Coast of California through the mid-1980s, before they switched professions to save money to purchase their own vineyard.

In 1995 they purchased a 20-acre property with 5 acres of recently planted Syrah and Zinfandel on their own roots. In 1996 and 1997 they made further plantings, expanding the total vineyard to 13 acres. They commuted each weekend from San Jose, Calif., to the vineyard, moving there in 1999.

Lachs and Marks soon realized big changes had occurred in the industry between 1983 and 1993, and many were in viticulture rather than winemaking.

After investigating new vineyard developments, and I am pleased to say read my book *Sunlight into Wine* as one of their key references, they planted varieties not common in the Sierra Foothills. They were determined to evaluate a range of trellis systems in their new vineyard, and Bill Naylor of Naylor Farms in Fair Play, Calif., was hired as vineyard manager and consultant.

The vineyard

The vineyard site has primarily south-facing exposure (9 acres) at 2,500 feet elevation, among the higher vineyards of the region, 2 acres facing north and 2 acres facing east. The landscape has granite outcrops, and the soil is decomposed granite. The tractor rows are 11 feet wide, and vines are spaced 7 feet apart, although on some of the steepest slopes the spacing is 12 x 8 feet.

Varieties planted include Cabernet Sauvignon, Grenache, Syrah, Viognier, and Zinfandel. Two additional acres of Zinfandel and the Grenache were grafted onto the preferred 110R rootstock. No more 110R was available, and the Cabernet Sauvignon and Viognier were grafted onto more vigorous rootstocks 5C and 5BB when planted.

The historical annual average of length of harvest to achieve optimum maturity of the five grape varieties is 34 days, harvest in 2014 was 30 calendar days. Harvest in 2013 was 20 days. "Historically, we are a high Region 2 or low Region 3 climate," says Lachs. "At our elevation, we experience low humidity during the growing season."

About one-half of the grapes are sold to other wineries, the remainder used for winemaking under the Cedarville Vineyard brand. The vineyard is farmed organically, with strict sustainability motives in mind.

By and large the vineyard has been vigorous, which led to review of Lachs' irrigation practices. A neutron probe service is used to assist in irrigation scheduling.

Because of the drought in California, water availability from a well is limited, and this led Lachs to delay commencing irrigation until July 1. In 2014 he reduced water use by 70%, and the delayed start to irrigation is a significant contributor.

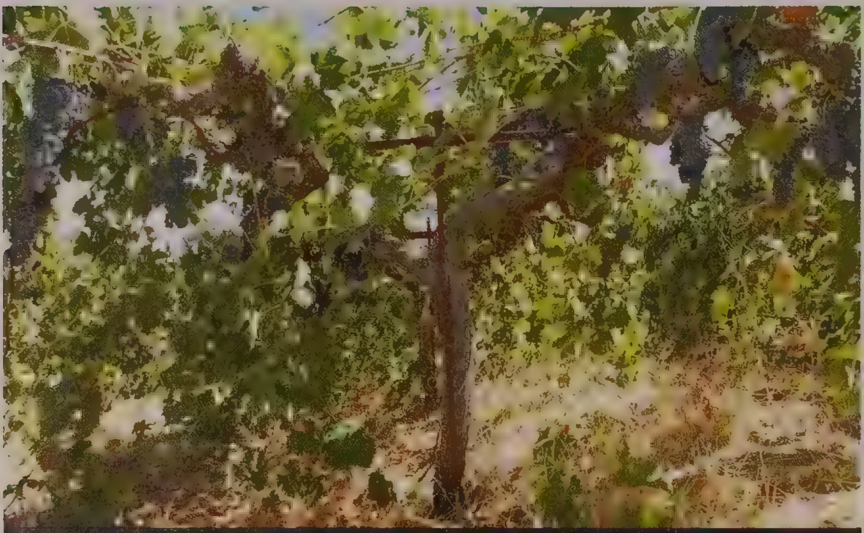
Annual rainfall in south El Dorado County is historically about 35 inches, but was only 32, 28 and 23 inches in the last three years.

"The property was previously pine and oak forest, and the soils had naturally good vigor," says Lachs. "Vigor has diminished over time, which led us to supplementing our soil with compost, manure and cover cropping."

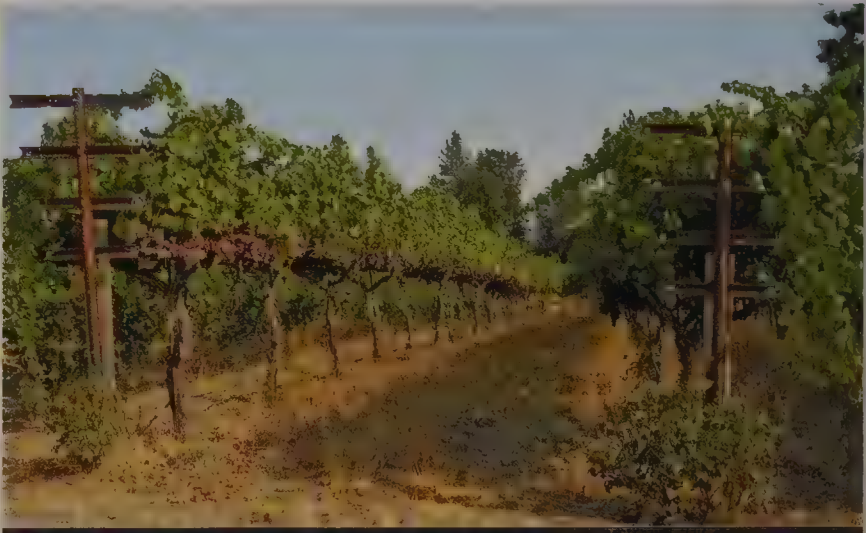
As for many California growers I meet, Lachs uses a long irrigation cycle of two to three weeks. I challenged him that this was using his drip-irrigation system as a flood-irrigation system, by adding infrequent irrigation with large volumes.

Drip-irrigation systems are designed to allow frequent irrigation of small amounts of water. I encouraged him to investigate irrigating every two to three days with small volumes of water, which would allow better control of vine vigor

Head-pruned and spur-pruned Zinfandel vine.



Quadrilateral-cordon GDC Syrah, east-west vine rows.



Quadrilateral-lyre Grenache, north-south vine rows.

by irrigation. This may well solve his vigor problem. (See "Vineyard Irrigation the Smart Way," in the October 2013 *PWV*.)

Vine-training systems

Lachs and Marks did not intend their vineyard to be an experimental farm. They chose what they thought would be the best training system for each variety, but there are no "control" blocks, and so no comparisons can be made apart from between varieties and training systems.

Syrah was planted on some of the steepest ground, and the vine rows were terraced. The vines were trained to the California "quad" system with four high cordons trained 5 feet above ground, on average, and 42 inches wide. The height of the cordons varies on the steep, terraced hillsides. Because of pruning and shoot positioning, the shoots grow downward.

Lachs reports that this system is achieving good ripeness. Initially they thought there would be a need for more crop thinning, but this has turned out not to be the case. The so-called "California quad" is in fact the geneva double curtain (GDC) system renamed.

The GDC was developed by professor Nelson Shaulis in New York state. In my experience this trellis system is very well-suited for high-vigor vineyards. This is because the downward growth of shoots helps to devigorate them. Also, there is good fruit exposure with this system. I frequently recommend the GDC for high-vigor red grape vineyards, where substantial improvements in yield and quality are forthcoming.

Lachs and Marks predicted even

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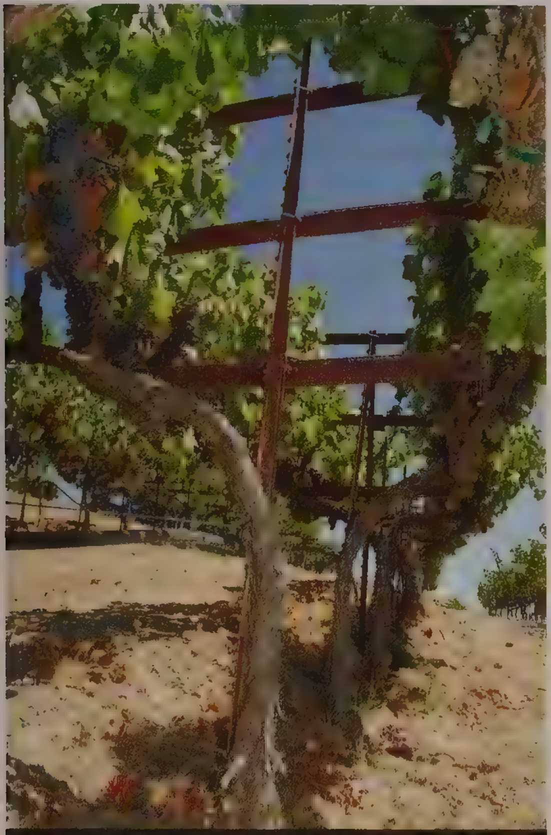
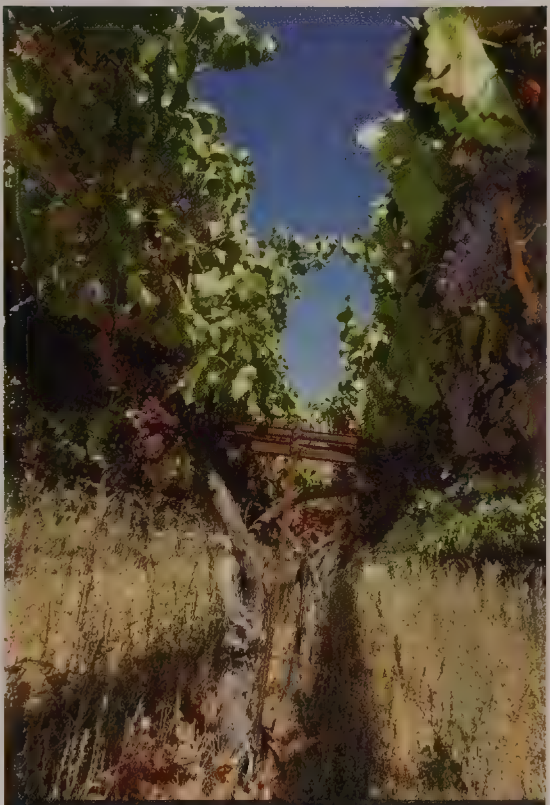
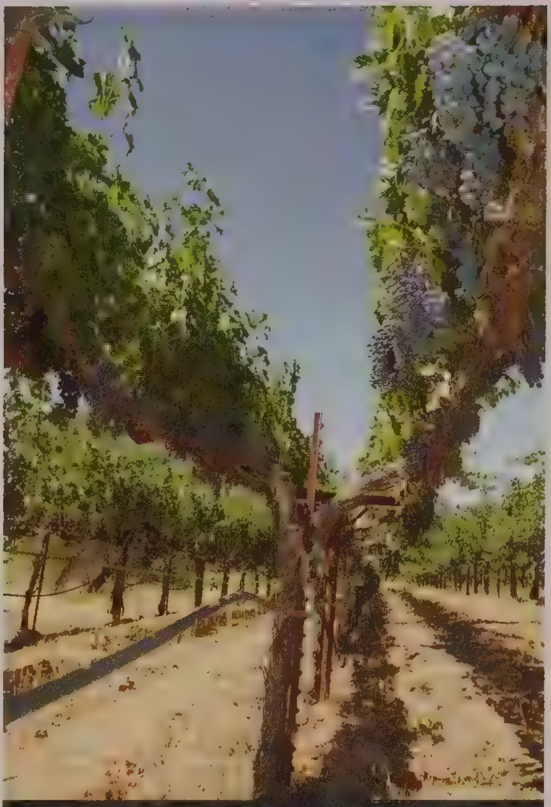

Bilateral cordon Grenache, east-west rows.


Quadrilateral-lyre Grenache vines in north-south row orientation.


Quadrilateral-lyre Cabernet Sauvignon, east-west vine rows.

larger vigor problems with Grenache. This is an interesting variety with large bunches and large berries, and the wines can be poorly colored unless the vines are well managed. In the hope of devigoration, they reduced the normal vine spacing in the row to 3.5 feet between vines.

I do not agree with this approach. In my experience, close spacing in the vine row is the principal cause of excessive vigor, as the vines get into a vegetative growth cycle, and yield and quality typically decline. This concept is well covered in my book, *Sunlight Into Wine*.

My approach in many vineyard situations is to **remove every second vine** to increase the vine spacing. A recent

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column about double-header pruning illustrated this principle for cane-pruned vines. (See "Double-header solution for high-vigor vines in cool climates," in the July 2013 *PWV*.)

The Grenache trained to the lyre system has performed very well. The divided canopy has given more color to the fruit and allowed better spray penetration, which is important for control of powdery mildew and botrytis.

Viognier was originally trained to a vertical shoot positioned (VSP) trellis with a bilateral cordon using steel highway posts. This block is on a north-facing slope, and there is no water available for frost protection. In two out of three years there has been frost damage, and the crop load reduced to half of normal.

In an effort to overcome the potential frost problem they have gradually introduced cane pruning, which they find can better accommodate frost damage. Lachs emphasizes that this is not a rigorously shoot-positioned VSP; it may be described as a "lazy VSP" that allows more sunlight to create dappled shadows in the fruit zone. This system provides for good fruit exposure, which is not always seen with VSP-trained vines.

Cabernet Sauvignon is trained to a traditional lyre system, 3 feet wide at the base and 4 feet wide at the top. These vines have good vigor. In the east-west vine rows, the owners notice a difference in the canopy on the north and south side. The south side canopy shows early basal leaf yellowing, obviously some response to more sunlight. Therefore the owners decided to avoid too-strict shoot positioning and leaf removal on the south side of the vines.

Zinfandel vines at Cedarville are head-trained and spur-pruned. The vines are given a lot of leaf removal and fruit thinning including the removal of shoulders of clusters, especially of second crop. I have seen Zinfandel grown very successfully on a lyre trellis. Fruit coloration is very sensitive to sunlight exposure.

Crop Load Summary (in tons per acre)
Total Vineyard = 13 acres

	2010	2011	2012	2013	2014
Viognier, 1 acre	3.0	3.25	4.5	4.6	4.54
Cabernet Sauvignon, 3.1 acres	2.3	2.6	3.0	4.4	4.2
Zinfandel, 5.6 acres	2.6	1.9	2.02	2.34	2.5
Grenache, 1 acre	4.0	3.5	3.3	3.75	3.67
Syrah, 2.3 acres	2.8	3.0	3.7	4.2	4.0

"Lazy" VSP cane-pruned Viognier vine.

Conclusion

The standard trellis in the region for new vineyards is a bilateral cordon with VSP, although some older vineyards have the "Californian sprawl." There is a tendency for new vineyards to be planted to narrow tractor rows of 6 to 8 feet wide, corresponding to the availability of a narrow tractor.

Lachs and Marks have been encouraged by their vineyard experience with several training systems. Cedarville wine quality is well-recognized, and from that viewpoint they should be happy. It is unusual to see a vineyard where owners have deliberately set out to try a range of training systems. More commonly there is a "cookie cutter" approach with the same training system used irrespective of variety, rootstock, row orientation and vigor. Typically that system is the VSP, a system that is less well-suited to high-vigor vineyards.

The opportunities to improve yield and quality by altering training systems are well-documented although not always appreciated and applied by vine growers. It is a shame, they could produce more income from their vineyards. PWV

Dr. Richard Smart is rewriting and thoroughly revising "Sunlight into Wine." Interested persons should contact Dr. Smart by email at richard@smartvit.com.au. Dr. Smart visits the U.S. frequently, and consulting appointments also can be made by email. See smartvit.com.au.

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» CHAPTER FOUR «

Myths of Frost Protection

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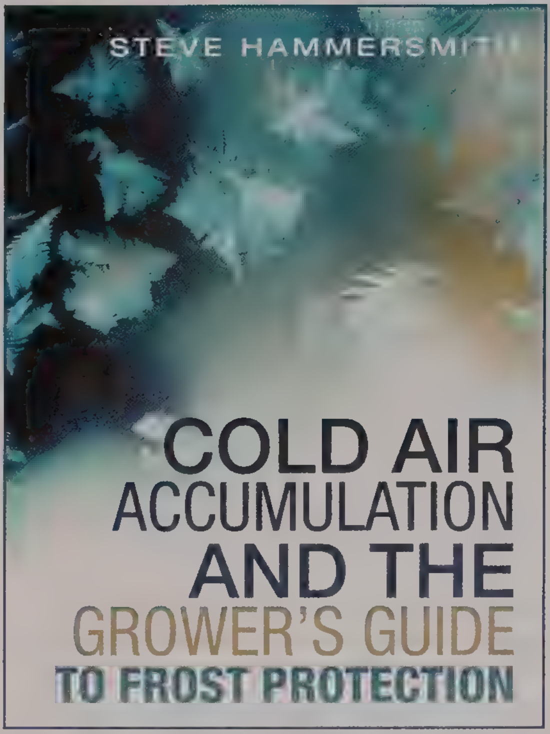
STEVE HAMMERSMITH
COLD AIR ACCUMULATION AND THE GROWER'S GUIDE TO FROST PROTECTION

BY Steve Hammersmith

Below is an excerpt from Cold Air Accumulation and the Grower's Guide to Frost Protection, Chapter 4, *available from Westbow Press, 85 pages, $31.95 (Paperback), $3.99 (Ebook).*

MYTH—Cold air that causes damage "falls" from the sky and settles in the low spots.
Reality—Cold air that causes frost damage is cooled by the ground and flows along the ground downhill into accumulation areas due to gravity. The cold air is the result of the ground losing heat through long wave radiation during nights that have no wind and no clouds. The ground will lose heat at a faster rate than the air and as the ground loses heat and cools, it in turn cools the air closest to the ground.

Colder air molecules are heavier and denser than warmer ones and will stay closer to the ground. The lower, colder molecules are affected by gravity. Cold air will begin to move downhill until insufficient drainage conditions such as physical obstructions or low slope impedes the flow and causes the cold air to accumulate. When the cold air builds up deep enough to submerge plant tissue frost damage may occur.

Cold air masses that come in over the ground due to a weather system and are below the critical temperature for the crop to be protected are rare. Even though there are the characteristics of radiation frost-clear skies and no wind, this is a regional frost event that is the result of a cold mass of air associated with a winter storm or advection freeze.

When these types of events happen more frequently than is economically viable, then the grower must consider that the crop he is trying to grow is not suitable for the region and make adjustments.

MYTH—Blowing wind over vines will prevent frost.[1]
Reality—Blowing air or otherwise disturbing plant tissue while it is in a super cooled state will promote frost damage by stopping the super cooling process causing ice crystallization in and around the cells.

In order for wind to be effective, there must be warmer air from the higher layers pushed down and mixed with the colder air to increase the overall air temperature, or heat must be added to the blowing wind. It is the rise in temperature produced by mixing warmer air molecules with the colder air molecules close to the ground that protects against frost, not the movement of air.

MYTH—Smoke protects against frost.[2]
Reality—Smoke does nothing to stop or slow heat loss from the ground. On the contrary, smoke does prevent heat from reaching the ground when the sun comes up in the morning. Smoke is not only useless in protecting against frost, it is a detriment.

The ground loses heat through long wave radiation which is approximately 10 to 15 microns in diameter. Smoke particles can be less than 1 micron in diameter. Smoke does nothing to stop, absorb, or reflect radiation losses from the soil. It is invisible to the long wave radiation and has no impact on ground cooling or the resulting cooling and stratification.

When the sun comes up in the morning, the heat radiated back to the ground from the sun is short wave radiation. Short wave radiation is approximately 1 micron in diameter and is effectively blocked by smoke. This effect will delay the warming process.

Smoke can be useful when using heaters for frost protection to indicate the height of the stacking of the molecules. When using heaters for frost protection, the stacking point of the warmed molecules is a ceiling. When heaters warm the air, the difference in temperature between the heated air molecules and the natural surrounding molecules will cause the warmer molecules to rise. This effect is called "heat buoyancy." The warmer air molecules will rise, and quickly lose heat, to a height where they are "neutrally buoyant," or the same temperature as the air around them.

For example, since a molecule of 32° F will not push away another molecule of 32° F (the same temperature and density), the upward rising molecule will stop when it is blocked by a natural molecule of the same density- a process called "stacking." This point at which the heated molecules stop rising is the "ceiling."

The process of heating molecules and stacking them at a given height creates a thermal boundary line. The newly stacked molecules will then begin to cool and move downward again in a convection manner until they are reheated by the heat source and rise again.

> One use for smoke particles is that they will move horizontally along the demarcation line (thermal boundary line) and give a visual representation of the height of the "ceiling."

Smoke particles will rise with the rising warm air molecules and will move horizontally along the thermal boundary line giving a visual representation of the stack height of the heated molecules. The temperature from the heaters can be adjusted up or down as necessary to achieve the proper ceiling height.

MYTH—Frost on the ground indicates a frost problem.
Reality—Ice on the ground is not an indication of frost damage on the plants. It is the deepening mass of lethal cold air that causes frost damage, not the temperature of the ground.

The ground in all areas of the vineyard

will give up heat at the same rate (providing all other factors of soil density, moisture content, etc. are the same), and the ground will cool at the same rate. Areas that are well drained are not generally at risk for frost damage because there is no cold air accumulation.

The ground temperature on a hillside is approximately equal to the ground temperature in the lower valley, but the cold air generated by the cool ground on a hillside flows off and does not build up deep enough to submerge plant tissues. The natural drainage capacity on the slopes prevents cold air accumulation and avoids the buildup of cold air.

MYTH—Removing the downhill barriers such as trees and brush will improve cold air drainage.

Reality—Downhill barriers can sometimes block cold air that builds up below from flooding back into the vineyard and block the cold air generated from above from draining out.

Cold air accumulates in areas of insufficient drainage. If the basin area below the vineyard has cold air from surrounding sources that exceeds the capacity of the basin to drain itself, cold air will build up from below. This rise in the height of the cold air mass in the lower basin will cause cold air to flood back into the vineyard unless it is blocked from below and removed. A barrier along the lower portion of the vineyard may help to inhibit cold air entrance into the vineyard and be a benefit.

One way to tell when there is insufficient drainage and flooding from below is that the air temperature in the lower basin will be equal to or lower than the temperature in the vineyard, and the temperature in the lower basin will drop prior to the temperature in the higher vineyard.

In other instances, the basin below the vineyard is well drained and the cold air that is causing frost damage is originating from the vineyard area itself and/or areas above the vineyard. Cold air flowing downhill may not be building deep enough to cause damage until the downhill barrier obstructs the natural drainage causing accumulation of cold air in the vineyard which is a cold air lake.

If there is adequate drainage below and cold air accumulation is caused by the barriers, the temperature in the lower basin will be higher than the temperature in the vineyard.

Often, both cases will exist. Under mild frost conditions there may be adequate drainage in the lower basin due to a smaller volume of cold air being generated from the surrounding areas that flows in there, while under severe frost conditions the lower basin will be overwhelmed and accumulate cold air due to the larger volume of cold air flowing into it. When the inflow of cold air exceeds the capacity of the basin to drain itself, accumulation will occur.

Frost protection, spring 2008.

PHOTO BY STEPHEN STERLING OF ESTERLINA VINEYARDS & WINERY

MYTH—Cold air is like water.

Reality—While there are similarities in the way that cold air flows under stratified conditions as compared with the flow of water, there are also some differences. Both water and katabatic cold air flows are caused by gravity and so they will both follow the path of least resistance. Some of the differences between air and water are:

1. Water does not change viscosity with temperature change, until it freezes or evaporates.
2. The density of air changes in direct relationship to its temperature. The colder the air, the more dense it is and the heavier the molecules. This characteristic guarantees that the coldest air molecules will always be lower than warmer molecules under natural conditions. The heaviest water molecules are at +4° C (approximately 39° F). As water cools on top of a lake, it becomes heavier and sinks. At lower temperatures, it becomes less dense and rises again. If not for this characteristic, ice would form at the bottom of pool of water, not on the top.
3. The speed of air flowing downhill is determined by the slope angle, ground surface (smooth, slick surfaces produce less friction) and differences in viscosity caused by air temperature and absolute humidity. The speed of water flowing downhill is determined by slope angle and the ground surface. The temperature is not a factor.
4. Cold air running into an obstruction can build up to three X or four X the height of the obstruction before spilling over. The height that the cold air will build to is determined by the angle of the slope approaching the obstruction, viscosity of the air, and the volume of air flowing to and blocked by the obstruction in relation to the available drainage capacity.

The lower the angle of approach and the lower the air temperature, the larger the mass of cold air that will be blocked by the obstruction. This will result in a higher cold air mass in relation to the height of the obstruction and cold air will reach further back and higher into the vineyard. Water running up against an obstruction will build up to the height of the obstruction and then try to flow over.

Water will also build higher than an obstruction to a lesser degree. If the volume of the water flowing to and blocked by the obstruction exceeds the available drainage capacity over the dam or barrier, there will be a depth to that flow over the dam. The resulting water level in the lake behind the dam will then be higher than the dam itself, but not to the same degree as cold air accumulating behind a dam.

MYTH—More and hotter heat is better than less heat.

Reality—Applied heat that is too hot will rise quickly to great heights above the vineyard and have no effect in the growing zone.

As cold air molecules near the heat source are warmed, the warmer molecules become lighter and less dense than the surrounding colder air molecules. This causes the warmer molecules to be thermally buoyant and to rise.

The greater the difference in temperature between the heated molecules and the surrounding colder natural molecules, the more buoyant the warmer molecules will become. These molecules will quickly lose heat as they rise, and at some point above the ground, they will be the same temperature and density as the surrounding molecules.

> The greater the difference in temperature between the warm molecules and the cold molecules, the greater the tendency to rise, resulting in faster and higher ascendency of the warm molecules.

The height above the ground where the heated molecules no longer rise is referred to as the "ceiling" and this is where the molecules "stack" under the ceiling. Since molecules of the same temperature will not push away each other, molecules of approximately the same temperature will stack under each other until the temperature in the entire area below the ceiling is equalized.

The ceiling height can be controlled by modifying the amount of heat or heat concentration coming from the heat source.

A more indirect heat—or radiated heat—will impart the same level of heat energy (BTU's) over a larger area while turning the heaters down and burning less fuel will provide less BTU's. Either approach will provide less temperature difference between the heated molecules and the natural molecules resulting in less thermal buoyancy. This will result in a lower ceiling or "stacking" height. In most cases the ideal ceiling height is just slightly above the canopy.

Using more heaters, each with less fuel consumption will have the same effect as fewer heaters that have better radiation capability.

When the molecules at the ceiling begin to cool they start to fall until they are again heated by the heat source and the process repeats. This continuing circulation of molecules being re-heated, rising and falling is called "convection."

No real protection occurs until the convection and stacking process is complete.

If a molecule is heated with a direct concentrated and non-radiating heat source such as a bonfire, then the heated molecules will rise to a much higher level and may not have the time to stack or cool and circulate back down into vineyard. In this case, the grower will only have succeeded in heating the atmosphere above the vineyard making no impact on the temperature inside the growing zone.

The limit of the temperature rise inside a vineyard is the temperature at the ceiling. For example, if the temperature at 15 feet above the ground is 3° F higher than at ground level, and this is where the ceiling is set, then the maximum rise in temperature inside the vineyard will be 3° F. In order to achieve a higher temperature rise, then the ceiling must be raised which would require more fuel and more time for the stacking/convection process.

The thermal gradient (the temperature rise at a given height increment) spreads out as the height from the ground increases. For example, there may be a 3° F rise from the ground to 15 feet, but the next 15 feet may raise only 1.5° F, and the next 15 feet above that may raise only 0.5° F. Fuel consumption rises exponentially to the rise in temperature required in the growing zone.

In all cases using heaters, control of the ceiling height to accomplish specific goals is essential and more heat is not always better.

MYTH—Heating water will improve the effect of under-vine irrigation.

Reality—Heating water prior to applying it for under-vine irrigation provides little or no benefit.

Under-vine irrigation releases heat generated from the cooling and freezing of the water that is emitted or flooded over the ground. The heat that is released from the water is transferred into the surrounding air molecules, which then become thermally buoyant and rise until they are the same temperature as the air around them. At this point they will stack under each other creating a ceiling and begin convection.

The principle way that under-vine water protects crops is the same as the principle of heaters. The main difference is the intensity of the protection. Molecules heated by gas-burning heaters can rise high above the vineyard canopy while molecules heated by water will tend to rise only a few feet from the ground. The temperature rise in the vineyard in both methods is limited to the temperature at the ceiling height.

To accomplish heat release from the water in the most effective way, the water must convert to ice before it soaks into the ground. Heat released due to the water-changing state from a liquid to a solid is called the latent heat of fusion. The following formulas illustrate the potentials:

Water state changes that will release heat and warm the air—

1 pound (approximately 1 pint) of water is cooled by 1° F = 1 BTU heat released.

1 pound of water changes state from liquid to solid (ice forms) = 144 BTU's heat released.

1 pound of water is condensed from a gas state (as when dew forms) = 1,077 BTU's heat released.

Water state changes that will use heat and cool the air—

1 pound (approximately 1 pint) of water is warmed by 1° F = 1 BTU heat used.

1 pound of water changes state from solid to a liquid (ice melting) = 144 BTU's heat used.

1 pound of water is evaporated from a liquid to a gas (evaporation) = 1,077 BTU's heat used.

Achieving a high conversion rate from liquid to solid, and condensation from water vapor to water are the most efficient ways of releasing the stored heat in water.

Heating the water will slow the time it takes for the water to reach freezing temperature. This delay will cause a lesser conversion rate to ice before the water soaks into the ground. When the water applied does not freeze, but instead soaks into the ground, the major source of heat and frost protection is lost.

MYTH—Heaters placed along the high side of a vineyard perimeter will cause heat to flow down and drift into the vineyard.

Reality—Heaters around the high perimeter create a thermal barrier and block cold air flowing downhill from entering the vineyard from the higher areas outside.

A thermal "wall" is created by placing the heaters at a close distance to each other along a perimeter boundary, usually along the uphill side, or the side facing a prevailing cold air drift. The heat from the heaters will not flow downward into the vineyard—heat only goes up, never down.

The effect is to heat the cold air moving in from outside the vineyard (due to katabatic flow or from a prevailing drift), and block its entrance by heating it and sending it upwards. Since it is this cold air that causes frost damage inside the vineyard, the avoidance of cold air entrance offers protection against frost damage.

The coldest air molecules are the ones closest to the ground. These cold air molecules will mostly avoid being heated and stopped because they will go under the heat wall, rendering this method only partly effective and hugely inefficient.

The same effect can be accomplished with forced cold air drainage and barriers at a fuel use ratio a fraction of that of heaters, and with much greater effectiveness.

MYTH—Natural ice formation on plants is good because ice formation releases heat and keeps the plants warmer.

Reality—Natural ice formation on plant tissues, or white frost, will cause damage at higher temperatures than black frost conditions related to low relative humidity.

During periods of low humidity where the temperature falls below the critical point but does not condense water or ice onto the plant, super cooling of the plant tissue is enhanced. The vine will experience less damage than if the dew point were higher allowing water and ice to form on the vine. Surface water on the vine, such as is left on after a rain will act as a stimulus for ice within the bud.

High relative humidity can have a similar impact on super cooling as surface water does. Ice crystal formation on the bud surface can serve to inoculate the tissue and canes.[3]

Natural formation of ice on vines due to water precipitation from the air or residual rainfall/irrigation water left on the vine is not the same as continuous over-vine irrigation for frost protection.

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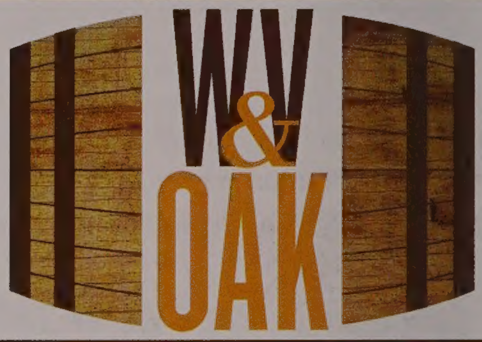

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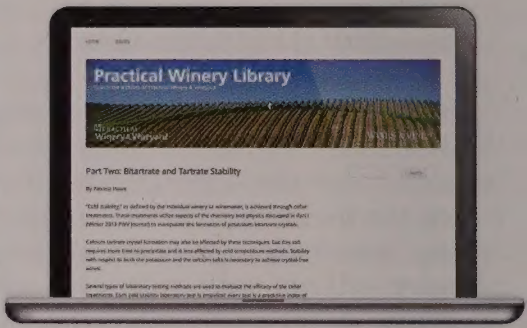

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